COMPUTER LANGUAGE™

VOLUME 4, NUMBER 7

JULY 1987

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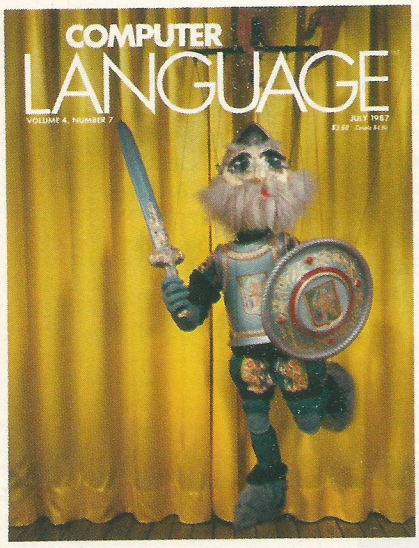

Sir Sampson Knight by Steven M. Overton
Olde World Puppet Theatre ©1982

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PROLOG and C Join Forces — 34
by M. Haytham Matthews
PROLOG and C may come from two different worlds, but here they were combined to take an application created on a LISP machine and reimplement it on a PC/AT. The result? A prototype so strong it went directly into the delivery environment on a trial basis.

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Multiway Branching in C — 75
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Guest Notes

After a protracted childhood in academia, AI is entering a tempestuous adolescence in the commercial marketplace. Like any fortunate child, its parents saw unlimited potential in their offspring; and, like any adolescent venturing out into the world, it has come up against an often less flattering, less indulgent reality.

While the core technologies of AI—symbolic computation, expert systems, and artificial vision, hearing, and speech—undoubtedly have a place in the computing mainstream, finding this place is not as easy as was once assumed.

Prototype systems, nurtured in the protective bosom of their inventors, are still by and large too green for actual deployment in the harsher, more demanding world of business. Unlike the academic computer community, business people don't always want interesting or challenging software. They have a business to run, not a computer.

This fundamental divergence in mindsets is one of the major factors still hampering the penetration of AI technology into corporate America. The commercialization of AI technology is an area where the nascent commercial AI community has a lot to to learn from its "conventional" brethren. Many—perhaps too many—AI companies seem to believe that AI-based solutions are somehow removed from the more mundane, practical issues facing the conventional programming community.

AI technology offers programmers tools to build software solutions to business problems currently unaddressed by more conventional techniques. Despite the aura of glitter and novelty, this technology is intrinsically no more difficult to learn than any other. However, if it is to be successfully integrated into the mainstream, the people currently making the corporate computer world function must be prepared to offer some significant help.

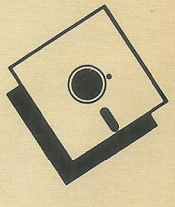
Return on investment is the touchstone by which the businessperson evaluates computer solutions. This doesn't mean simply selling AI-based solutions cheaply. It's more a matter of taking the already well-established base of knowledge about inventing, developing, managing, testing, implementing, and maintaining software in a business environment and applying this knowledge base to the new technology.

Obviously, there may be areas where new rules for evaluating, measuring, and tracking AI-based software projects are needed. Perhaps new methods for justifying the hardware and software purchases required to support these systems must be developed to properly evaluate what value AI-based systems can bring to a corporation.

If these sorts of changes are needed, so be it. They have a much better likelihood of being sold to the corporate decision makers who sign the checks if the people in the driver's seat of commercial data processing—those who have already proven that computers can be a powerful asset to the corporate enterprise—take the lead in understanding and deploying the new technology.

Philip Chapnick
Editor, AI EXPERT

COMPUTER LANGUAGE code can be obtained from CompuServe (type "GO CLM" at the prompt and you'll be in our SIG), USENET ("mod.sources"), and Bulletin Board Services in the U.S. and Canada. Bulletin board parameters are 8 data bits, no parity, 1 stop bit, full duplex, and 300 or 1200 baud.



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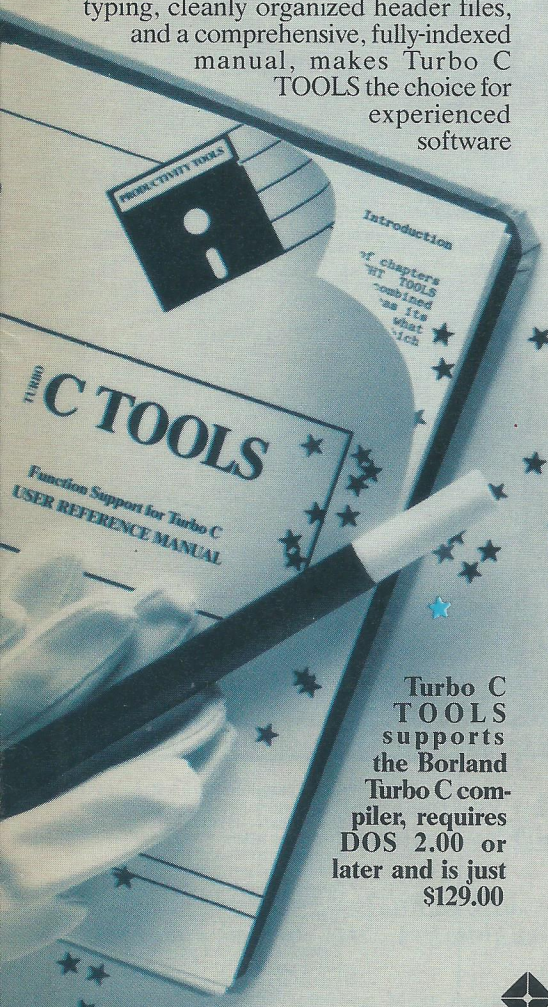

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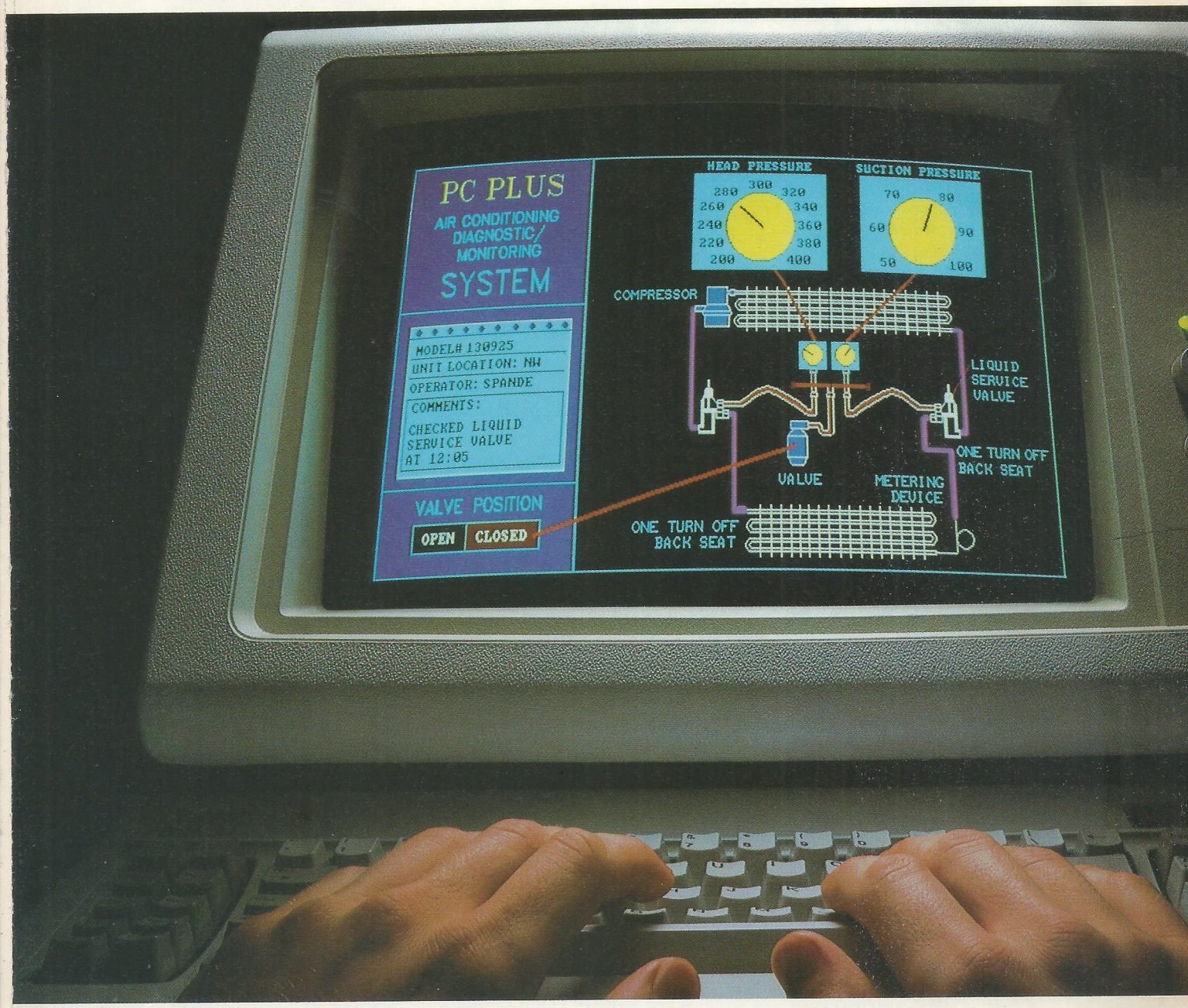

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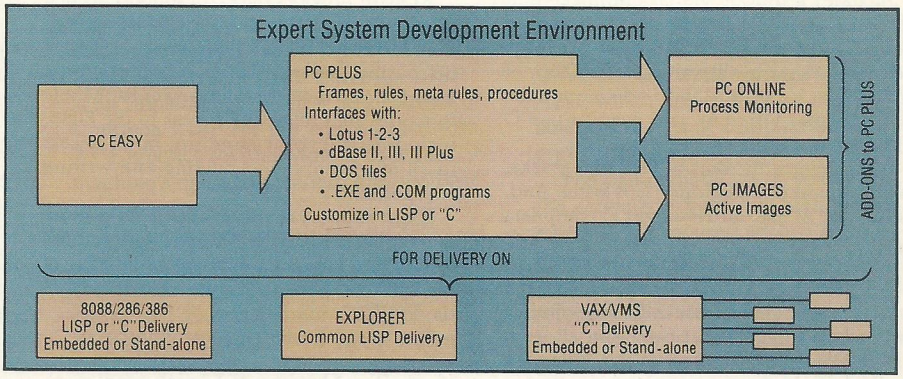

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by Roy Sherrill, President, Datalight

Microsoft purchased our C-compiler during February 1987 and we still haven't heard from them. OK, Microsoft, we are extending our challenge deadline from April 1, 1987 to May 15, 1987. After all, the Microsoft ad claims "the fastest C you've ever seen." Your reply, Microsoft!

Walter says Optimum-C is better

Walter Bright, the developer of Optimum C, says that Optimum C would win 7 out of 10 benchmarks as compared to Microsoft C, V.4.0. Walter explained to me that Optimum C includes a unique global optimizer that helps create compact code while increasing execution speed up to 30%. By the way, Borland, Walter is still waiting for his copy of Turbo C,® V.1.0. Borland's ad claims "the fastest, most efficient and easy-to-use C compiler at any price."

After reviewing Borland's benchmarks, Walter claims that Optimum C is faster. And, as for ease of use, all Datalight C compilers have been shipped with a free Learn C program for the last six months. Also, our new EZ Interactive Editor will show you each syntax error in your source code, then compile or "make" and run your program, all from within the editor. OK, so let the Microsoft challenge begin...

We only ask the following...

The benchmark suite will consist of the set of programs that Microsoft supplied to *Computer Language* for their February 1987 C compiler review issue. Microsoft will make available the programs to Datalight at least two weeks prior to the benchmarking. The benchmarking will be between Microsoft C 4.0 and Optimum-C. It will occur at a mutually agreed upon time and place. Interested individuals will be allowed to attend. The benchmarks will be compiled and run on a standard IBM PC-AT.

There will be two separate tests for each program: compile and link speed, and execution speed. For each test, a representative from each company will set up the compiler so that it performs at its best.

The benchmarks will be adjusted so that they take sufficiently long to run, that the tolerance involved in timing them is insignificant. The winner is determined by the compiler with the faster execution times for the majority of the benchmarks. We'd like an answer from Microsoft no later than May 15, 1987.

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COMPUTER LANGUAGE, February 1986

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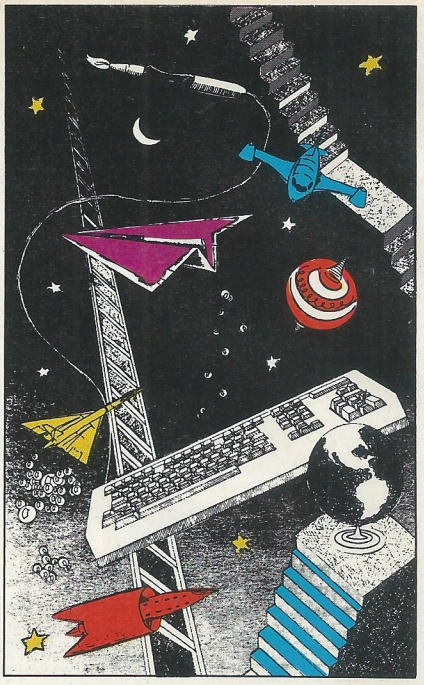


Artwork: Anne Doering

Z8000 defender

Dear Editor:

Having fought my own battles with Intel's militant segmentism, P.J. Plauger's "You must be joking" (Programming on Purpose, *COMPUTER LANGUAGE*, April 1987, pp. 15-19) temporarily changed a grimace into a smile. But I have to point out that it's not fair to find the Z8000 guilty of all of the problems that plague the Intel architectures simply because it too uses segmentation.

At this point in history we are all aware that the linear address space is an awful lot easier on programmers. However, Zilog made the Z8000's segments relatively benign. This microprocessor has 14 general-purpose 16-bit registers. It does not have specific segment registers. Instead, to use it in segmented mode, the general-purpose registers are paired, one providing an offset and the other the segment number, which can be interpreted as a virtual or real address by system hardware.

It is true that the Z8000 has some powerful auto-incrementing and decrementing instructions that will not function properly across a segment boundary, as we would like for accessing, say, an array larger than 64K. But, unlike the 8086 segments, the Z8000's segment register can be the destination of any arithmetic or logic operation, making an explicit carry from incrementing the offset a simple and painless matter. In particular, there is no need to dump another register just to have a scratchpad for address calculations.

It should be pointed out that the Z8000 still has seven truly general-purpose long registers even if all are doubled up for addressing. In contrast, the 8086 really has one general-purpose and six rather limited registers (not counting the stack pointers of either machine). We should also note that each of the Z8000's long registers has a completely independent segment component.

I think that the Z8000's limited market success should probably not be attributed to its use of segmentation but rather to other factors. Still, I want to thank Plauger for lambasting an architecture that has caused more programmers to tear out their hair than perhaps any other.

David McCracken
Aptos, Calif.

Software tools modified

Dear Editor:

P.J. Plauger named the following skills of a software engineer in "Which tool is next?"(Programming on Purpose, *COMPUTER LANGUAGE*, Feb. 1987, pp.15-16):

- Clear understanding of the software cycle: no code before its time.
- Know an accurate specification: don't start until customer signs off.
- Clearly specified deliverables: you must know when you are done.
- Know what adequate documentation is.
- Understand adequate testing.
- And, by the way, know how to design and code programs.

Software engineers, however, are beginning to grudgingly admit the obvious:

- "Plan to throw one away; you will, anyhow." (From *Mythical Man Month).*
- The design always requires changing the specification and the final solution is often found only after you have hacked up a failure. (See "On the Inevitable Intertwining of Specification and Implemetation" *Software Specification Techniques*).
- The customer will always have the last word when he or she sees the system run.

A good software engineer should, therefore:

- Avoid coding like the plague. It takes time and that is the software engineer's most precious commodity. Have your own software tools available or beg, borrow, or buy someone else's.
- Use quality tools to hack up a quick prototype. This is the throwaway version that is built in days or weeks instead of months or years.
- Modify the prototype until the customer is happy. Notice the stuff the customer likes to change and make sure it is client controllable in the delivered product.
- Use performance analysis tools to evaluate throughput and fix or plan to fix bottlenecks. Even with today's hardware, you can't sell a pig.
- The prototype demonstrates the architectural concept, performance characteristics, projects that must be initiated for the final product and yields pretty accurate estimates of the time required to deliver. Now you just follow your nose.

While all this may look like a hacked up version of a software engineer that should probably be thrown away, I submit that the real world is very messy.

Jeffrey V. Sutherland, Ph.D.
Vice President, Product Development
The Saddlebrook Corp.
Cambridge, Mass.

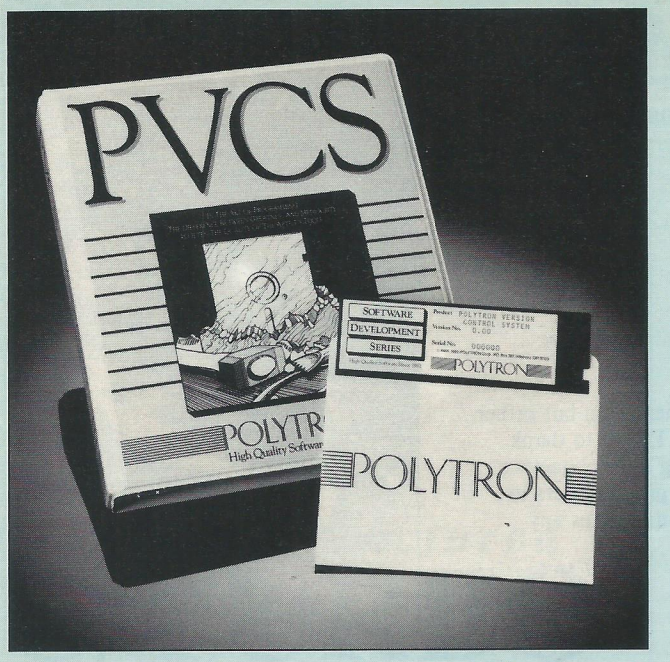
Stallman's response

Dear Editor:

John Heselton's letter "Brilliant but naive"(Feedback, *COMPUTER LANGUAGE*, May 1987, pp. 9-15) shows how a person starting with a basic antipathy to the idea of sharing can misperceive any dissent as the most ludicrous possible strawman. An example of this view is a slave, someone who is forced to do specific jobs by a master. I've never said anyone should be forced to be a programmer or that programmers should never be paid. I am against certain ways of raising the money to pay them, but not all ways.

Heselton's comparison of free software with free gasoline is a good one. Expecting free gasoline is silly because gasoline is used up as you drive and cannot be trivially copied. If software were like that, free software would be silly too. By the way, the "free" in free software refers to freedom, not zero price.

Richard Stallman
Cambridge, Mass.



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Stallman criticism

Dear Editor:

This letter is to thank John Heselton for his letter "Brilliant but naive" (Feedback, *COMPUTER LANGUAGE*, May 1987, pp. 9-15). I'm glad someone had the words to defend programmers from the jaws of poverty.

Heselton's letter was in response to a previous article by Judy Getts, "The last true hacker: Richard Stallman" (Computervisions, *COMPUTER LANGUAGE*, May 1987, pp. 99-107). Stallman's belief that programming is a service, not a product, is incorrect. A service cannot be put into a can and sold. A program can. To say that this end product should be free is ridiculous. Why would anyone pay for a product to be developed just to have the next person get it for free?

I agree, Stallman is probably very brilliant. I think if he and I had a war of words, he would probably win. But to say he is naive is putting it mildly. Richard, open your eyes! Money makes the world go around. I know I wouldn't stay with a programming career if all I saw in my future was an hourly wage.

Steven M. Sommers
Orange, Calif.

Wrap-up rebuttal

Dear Editor:

"Fourth generation language data bases" by Richard Finkelstein, William Patterson, and Kasu Sista (Software Reviews, *COMPUTER LANGUAGE*, May 1987, pp. 89-122) was interesting and informative. However, you omitted ORACLE (ORACLE Corp.), the best known and most widely used such product.

In so doing, you rendered the article imcomplete in two ways. First, an objective and thorough review of ORACLE would be more valuable to your readers than one of any other single product. Most of us know its reputation; we would like to know the facts.

Second, ORACLE is as close as you can come to a standard of reference; it would have clarified how all of the products compare to each other. This latter purpose would also have been served by much more detailed tables of product features. For example, how complete are the implementations of SQL? Are nulls and assertions supported?

Finally, although you do not have space to review every product in a given field, you should at least list all of the major ones, compare them in general terms (for example, include them in your feature tables), and indicate why you chose to review the ones you did. I find it strange and arbitrary that there is no mention of PARADOX.

Eric Rosenberg
Greenwich, Conn.

Reviewer Richard Finkelstein responds: ORACLE was identified as a product that should be reviewed, but ORACLE Corp. declined to offer to be reviewed since v. 5.1 of ORACLE was in beta testing. I agree that this product should be considered for a future review.

As I mentioned in the introduction to the wrap-up, we chose products that were non-procedural and set-oriented. PARADOX is highly procedural (except for its query language) and differs little from any of a dozen products on the market with a similar type of language and applications development structure. While PARADOX may provide advantages over its competitors, it is difficult to find anything in the language that can be considered non-procedural or fourth-generation-like.

While I consider a comparison of SQL important, there were several packages reviewed that did not support SQL, and therefore, a comparison was inappropriate for this wrap-up. It may be an interesting topic for a future article.

Quicksort discussion

Dear Editor:

In the past few months, there have been several comments concerning the possibility of implementing Quicksort for linked lists. First, in his response to Bob Gebelein's letter "Unraveling unshuffle" (Feedback, *COMPUTER LANGUAGE*, Jan. 1987, pp. 7-10) Art Kagel states that "Quicksort cannot to my knowledge be implemented for linked lists." In a response to this statement ("Sorting it out," Feedback, *COMPUTER LANGUAGE*, Mar. 1987, pp. 9-11) Steven Kienle states that it could be done if the sort routine first copied the linked list to an array, sorted the array, and then copied the array back to a linked list.

While this is certainly one way to implement Quicksort for linked lists (and possibly the only way if working with a singly linked list), it is not always necessary. It is possible to implement Quicksort so that it works directly with doubly linked lists.

(The implementation I am discussing refers to doubly linked lists that have both a beginning and an end with *NULL* terminators at those points. However, the algorithm can easily be changed, and has been, to work with circular, doubly linked lists.)

There are two major problems with implementing Quicksort for linked lists.

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* March 10, 1987 issue, page 278.

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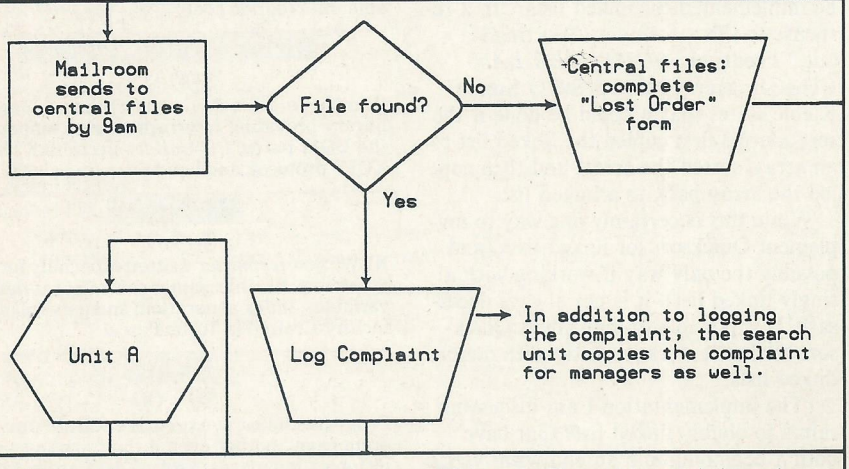

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First, the sort must be able to traverse the list both from beginning-to-end and end-to-beginning. Second, the sort needs to know when the pointer list from beginning-to-end passes the pointer traversing the list from end-to-beginning.

The first problem is easily solved by the use of a doubly linked list. At first glance the second problem would seem to preclude using Quicksort on linked lists. After all, how does the sort know when two pointers have passed each other in relative position within a linked list?

It turns out that solving the second problem is not really very difficult. Essentially, the sort routine logically maps array index numbers to the linked list elements. To do this, it needs only two additional, easily attainable items of information about the list: the relative index numbers of the beginning and ending elements of the list. These are passed, along with pointers to the beginning and ending elements of the list, to the sort routine. The routine matches each index with its corresponding pointer and, whenever a pointer is assigned to the next or previous list element, the corresponding index is incremented or decremented, respectively. By doing this, the test to see if the two pointers have passed each other becomes a simple relational test between the two indexes.

Quicksort can be, and is, implemented for doubly linked lists. The implementation given here has proven very useful in the projects I have worked on. It is easily extensible to secondary and other sort keys. Also, by using multiple sets of forward and backward links and making some modifications to the code, multiple sort orders of the list can be maintained while keeping only one copy of the data. This is especially useful when the data may be sorted and resorted several different times by an application (as when displaying tabular data to a user).

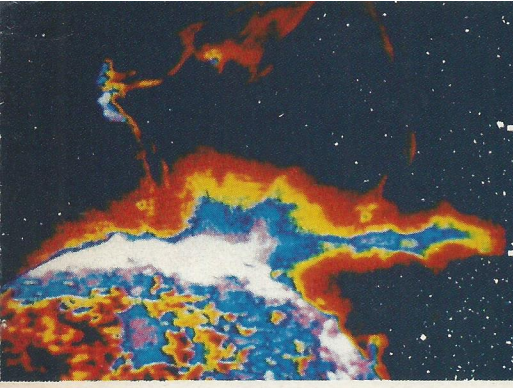
Mike Higginbotham
Plano, Texas

Clarifications

Dear Editor:

At last! Joseph Sant's "A Simple Data Compression Technique" *COMPUTER LANGUAGE,* Mar. 1987, pp. 65-66) is an article fully comprehensible even to me. Sant's text compression utility is easily understood, small-sized, and works most rapidly indeed.

Since I am a bit of a novice with any language, especially with C, my most recent, it came as something of a surprise that the compression algorithm is just a fraction too simple. Like most other typists, I cannot overcome the habit of pressing the space bar twice at the end of each sentence. Word processors that jus-



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tify text insert many extra spaces between words. The program as printed will delete only the first space, regardless of how many follow it.

The addition of one extra variable, *next*, and and a short *while* loop cures this problem:

```
...
if ( c == ' ')
   {
      prev_chr = 128;
      while (( next = getc(infile))
         == ' '); /* do nothing */
      c = next;
   }
...
```

The *while* loop simply gobbles every space after the first, terminating when it hits a non-space character.

Frank Slavin
Rural Retreat, Va.

[redacted] license required

In the general information table that appeared in "Moving Applications from dBASE to C" (COMPUTER LANGUAGE, *May 1987, pp. 67-73) under the heading "One-time cost—Royalty," there was an incorrect entry for Computer Control Systems Inc. Application programmers using products in programs for resale from the company do need to obtain a software license agreement as stated.—Ed.*

[redacted] Finding ddb

The ddb UNIX debugger mentioned in David Livshin's "A Source-Level Symbolic Debugger for UNIX" (COMPUTER LANGUAGE, *June 1987, pp. 53-56) is marketed by Charles River Data Systems as esdb (extended symbolic debugger). The product is part of UNOS, a UNIX V real-time operating system.*

For more information contact Dick Swee at Charles River Data Systems, 983 Concord St., Framingham, Mass., (617) 626-1111.—Ed.

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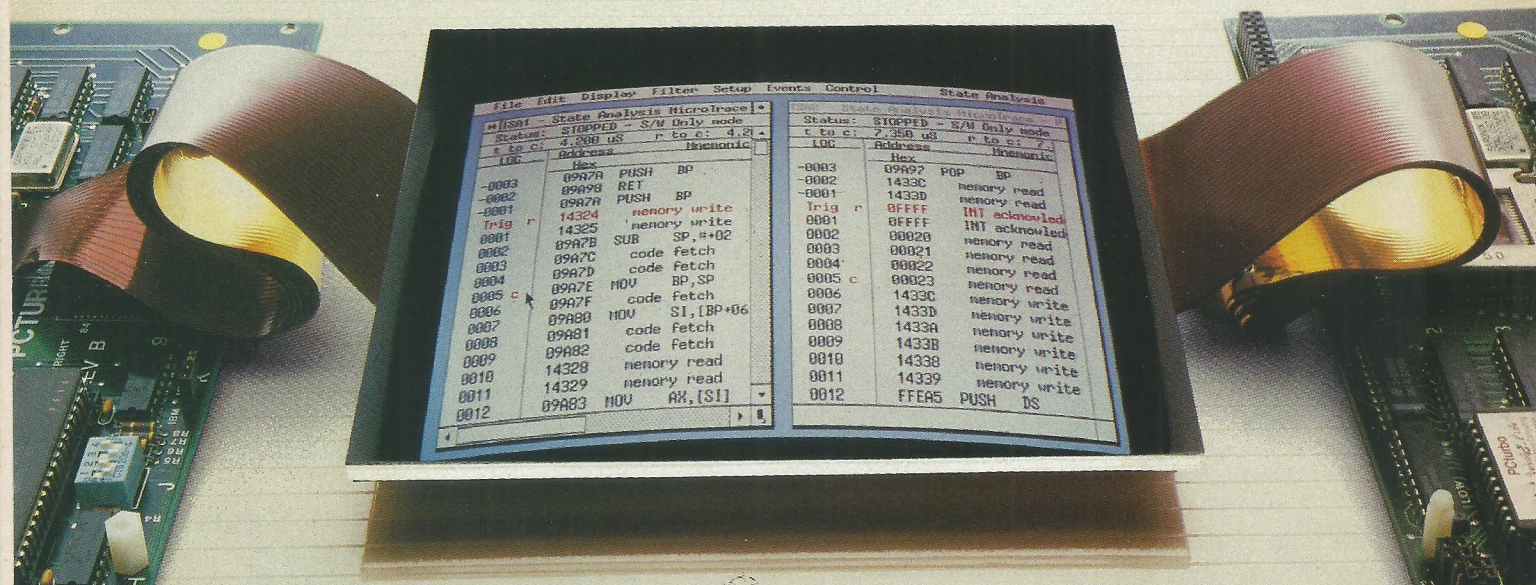

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PROGRAMMING ON PURPOSE

Who's the boss?

By P.J. Plauger

Method:
Top-down design

Description:
Top-down design focuses on the decomposition of a program into a hierarchy of modules. It can be viewed either as a process of refinement by steps, from the most general to the specific; or it can be viewed as a technique for mapping a data flow network into a hierarchy of modules. The name derives from the convention of drawing hierarchical decompositions of functions with the most general modules (the root of the tree) at the top and the most detailed modules (the leaves) at the bottom.

Mapping data flow networks is the safer way to evolve a hierarchy of modules, because it offers several models for proven solutions based on frequently occurring network topologies.

Documentation:
A data flow diagram retains the most information about a modular decomposition. At the procedural level, a structure (or HIPO) chart documents the modules and data interfaces of a given hierarchy.

Limitations:
Without a clear understanding of the flow of data at the appropriate level of abstraction, top-down design offers little guidance and leads to an excess of modules. Recursion can tie knots in a structure chart.

When I discussed bottom-up design several months ago ("Finite-state machines," *COMPUTER LANGUAGE*, Oct. 1986, pp. 15-19), I annoyed a number of people by focusing on the construction of finite-state machines. I know several other design methods fall under that name, but I didn't hesitate to apply the name to finite-state machines alone.

This month, I expect to annoy even more people by discussing top-down design almost purely in terms of data flow analysis. I know that for many readers top-down design is a blanket term that covers any of several right ways to do things. It is stepwise refinement, it is prototyping, it is goal-directed programming. I am willing to stipulate that top-down design is indeed all of these things, provided you are willing to concede that more guidance may be needed to turn an approach into a design method.

In my experience, the greatest guidance in elaborating a top-down design comes from an analysis of the flow of data through the program you are trying to build. The goal of top-down design is to produce a list of all the functions (routines, procedures, subroutines) required to perform a set of operations within one computer program.

In a computer program, one main function takes control when the program starts up. In turn, the main function calls all of the other functions, exchanging data in the form of arguments, function return values, and access to shared global data. At this level of abstraction the list of functions should be accompanied by:

- A list of the data passed into each function when it is called.
- A list of the data passed back from the function when it is called.
- A list of the shared global data that may be accessed or modified by the function when it is called.
- A brief (often one sentence) description of what each function does.
- A list of the functions called in turn by each function.

Essentially, all of this data can be captured on a diagram called a structure chart. IBM popularized a more stylized version of the structure chart, a Hierarchy with Input, Process, and Output (HIPO) chart.

Figure 1 shows a small structure chart. Each box represents a function, each large arrow a potential call to that

Simple structure chart

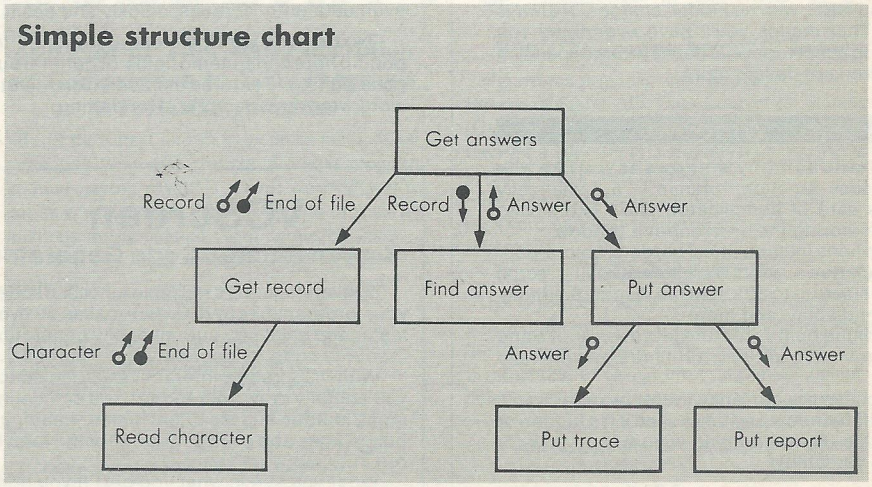

Figure 1.

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function from another function. Each small arrow is a data item that is read (down arrow) or written (up arrow) by the called function. As you can see, you can pack quite a lot of useful information into a structure chart.

The structure chart is an excellent document for capturing the initial design of a program. You have something concrete that is detailed enough to evaluate yet abstract enough to keep you out of the mire of implementation details. It is close enough to the everyday experience of writing code that many of us programmers can evaluate the likely success of the coding effort just from the data flow and function descriptions. Design quality can also be measured by a number of criteria that are applicable only after a structure chart has been generated. (They will be the subject of a future column.)

You are well-advised to maintain the structure chart throughout the lifetime of a program. Changes do occur in the number and nature of functions that constitute a program, but such changes are fewer than those that leave the structure chart unchanged. The effort of keeping the structure chart current is well repaid because you have a quick overview of the program and a handy road map to the functions and data that are likely to be affected by change. If the structure chart for a program is at all nontrivial, it is well worth generating and keeping alive.

So how do you go about making this marvelous document? The easiest way is to write the program, get it working, then document what you did. That puts the structure chart in the same category as, say, a cross reference of all identifiers defined in your program. It helps with program maintenance, but not with design. If you want to generate a structure chart as part of the design creation and evaluation process, however, you need a bit more guidance.

The HIPO approach is one attempt to add guidance. It tells you to write the main function box at the top of the page and describe its function the same way you would describe the overall function of the program. This description could be "produce graphs," or "update data base from transactions," or "perform Fourier analysis on spectra." You then identify three subfunctions that:

- Obtain input at the appropriate level of abstraction.
- Process the input to produce output.
- Deliver the output.

For each of these subfunctions, you then apply the same paradigm. For input functions, you ask yourself what three subfunctions are appropriate to obtain (somewhat less refined) input, do the process, and generate the (refined) output. For output functions, you ask yourself what three subfunctions will result in the production of somewhat less-refined output. And for process functions, you're on your own.

Eventually, you should arrive at a level where input/output can be performed in terms of the I/O services of the programming language you are using, and where all processing can be performed in terms of statements in the language or calls to standard library functions.

In real life, you probably discover the need for a few common subfunctions along the way and stop what you're doing long enough to go specify them. This is a way of bringing the bottom up to meet you, as it were, while you're mostly progressing top down. Nothing to be ashamed of—everybody does it.

Also, you shouldn't be too religious about decomposing each module into three subfunctions: input, process, and output. Often, one or two of these subfunctions becomes trivial long before you get to the bottom-most module for the third. If you find yourself making up silly little functions just to keep the hierarchy balanced, then you've fallen into the HIPO trap. As we shall see, there is no particular virtue in having symmetric structure charts. More fundamental forces are at work, shaping the hierarchy of a program.

A more important limitation of this approach to top-down design, as I have said before ("Which tool is best?," *COMPUTER LANGUAGE*, July 1986, pp. 15-19), is that it's easy to get lost on the way down. If the problem is small, you can usually succeed—but then the design method doesn't help all that much. If the problem is familiar, you can also succeed—but then you are primarily imitating a past design. What you need for big-league problems is a set of guidelines that let you:

- Make small problems out of big ones.
- Identify familiar problems within unfamiliar ones.
- Organize the smaller pieces into a coherent whole.

This is where data flow analysis moves to the fore in top-down design. With this approach, you first develop a data flow diagram for the problem to be solved. You then derive the structure chart al-

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most mechanically from the data flow diagram. The hardest part of the design, in fact, is hidden in the word "almost."

Of the many structure charts you can derive from a given data flow, you need some guidance to determine which is best. A data flow diagram is nonprocedural. It deals with the connectedness of the problem in terms of the data transformations that must occur, without breaking the problem into a hierarchy of functions. It is a natural by-product of the analysis phase before program packaging decisions come into play. It is often easier for civilians to understand a data flow diagram well enough to perform a constructive review than for them to understand the procedural description that implements the data flow.

I talked quite a bit about how to refine data flow diagrams in the last two columns on outside-in design ("Marrying data structures," *COMPUTER LANGUAGE*, May 1987, pp. 17-22, and "Divorcing data structures," *COMPUTER LANGUAGE*, June 1987, pp. 19-24).

In those columns I focused on breaking the data flow transforms into subnetworks of simpler transforms. Each simpler transform can be implemented with a single function whose structure is dictated by the structure of the data streams flowing in and out of the transform. You should always apply outside-in design repeatedly to a data flow diagram, before you begin top-down design, until you can make no further improvements.

Last month, I stopped just short of showing how to turn data flow diagrams into structure charts. Now you are ready to learn the great secret.

All you do is grab the data flow diagram by one bubble and shake it hard. The result, every time, is a structure chart that you can implement, does the job, and has the minimum connectedness required by the problem to be solved.

Figure 2 shows a typical data flow diagram that can result from data flow

All you do is grab the data flow diagram by one bubble and shake it hard

analysis plus the application of outside-in design. The double arrow indicates the module I chose as the grabbing point (C). With a flick of the wrist, Figure 3 results.

Outside-in design assures that each box in the structure chart performs one function that can be implemented by code whose structure captures the structure of the data flowing in and out (as arguments or calls to subfunctions). Data flow analysis assures that all necessary data sharing, and no more, is present. This is not just a top-down design, it is probably a good one.

I haven't told the whole story, of course. I gave no justification for my choice of bubbles to grab in Figure 2. The one I picked gave a nice-looking structure chart, but who is to say that it is the best? I could have picked the bubble below and to the left of my actual choice (E), or the one below that (F). Indeed, I have seen programs based on those choices, and they work. I could even have picked one on the fringes and make any of them work as well.

Figure 4 shows the structure chart that results if you choose the fringe module at the lower left of the diagram (G). Such modules are seldom chosen in real life to serve as the main function of a program hierarchy, but people seldom explore why that is so.

Believe it or not, you can truly pick up a data flow diagram by any of its bubbles, shake it out, and write a program that works from the resultant structure chart. What you find, however, is that some of the structure charts require more exotic coding than others to get the data to appear in the right place at the right time.

Data flow diagrams with merge points, like the two in Figure 2, cause one set of problems. Merges are reasonably well understood but still easy to get wrong. Most people automatically make a single merge point the main function of a program, and with good reason, as it turns out.

Data flow diagrams that contain loops are often even more troublesome because you have data that both merges and diverges at different points in the diagram. Designers usually fall back on various ad hoc structures to implement such data flows, and they often introduce an excess of data coupling between modules as a result.

So it turns out that all of the bubbles in a data flow diagram are equally valid candidates to serve as the main function of a program hierarchy, but some are more equal than others—just like the pigs and other animals in George Orwell's *Animal Farm*.

The data flow diagram will clearly show what data must flow to what modules to get the job done. What the data flow diagram doesn't tell you is how to coordinate the flow of data between modules. That's where you have to get procedural. And it is the procedural criteria, in the end, that determines who

Typical data flow diagram

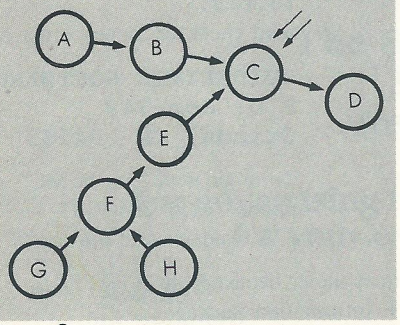

Figure 2.

Structure chart from Figure 2

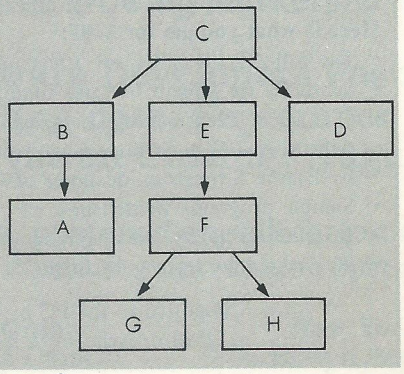

Figure 3.

Another structure chart from Figure 2

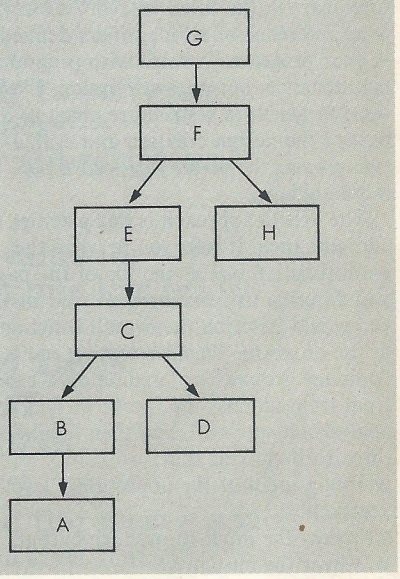

Figure 4.

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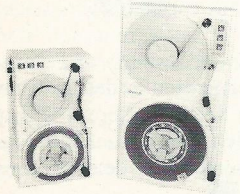

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CIRCLE 14 ON READER SERVICE CARD

should be the boss. All sorts of problems can crop up when you try to get the coordination right in a hierarchy. I just touched on some of them in conjunction with merge points and loops in data flow diagrams.

Most of the everyday issues, however, are really quite pedestrian. They have nothing to do with fancy connectedness. Rather, they arise out of the very modules we write all the time to resolve structure clashes and buffer or unbuffer data.

Last month I asked you to consider the effect on a module of making it an input function, a main function, or an output function. Figure 5 shows a very simple data flow diagram that could force you to confront such effects.

Depending on which of the three bubbles you choose as the boss module, the central module (B) can occur in any of three positions in the resulting hierarchy. Figure 6 shows all three possibilities.

Let's assume that B's role in life is to gather several records from A, assemble them into a combined datum, and deliver a stream of such combined data to C. If B is an input module, then C calls B every time it needs another combined datum. In turn, B repeatedly calls upon A until it has assembled a complete record. B then returns control to C with the combined datum as the function return value.

If B is the main module, it is built around a loop. While more input records can be obtained from A, the main module assembles some of them into a combined datum and calls C to dispose of the combined datum.

Finally, if B is an output module, it is called by A every time A constructs a record. B must maintain enough private memory to hold a combined datum, with notes detailing the state of that combined datum. B adds the newest record to the combined datum, calls C if the combined datum is complete, then updates its private memory so that it knows where to start the next time it is called. B then returns control to A.

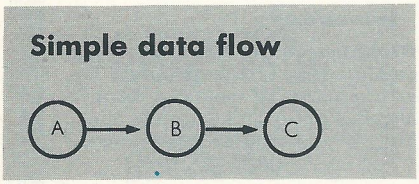

Figure 5.

Of the three implementations, the last is probably the most ornate. You can't avoid having private memory when B is an output module. You should know by now that having private memory incurs a maintenance cost that had better pay for itself by decreasing complexity somewhere in the design.

Any alternate hierarchy that doesn't need private memory should be favored. By this criterion, the implementation that has B as the main function is probably the least complex. (It may lead to higher costs for the other modules, but we'll get to that in a moment.)

The implementation that has B as an input module can be equally simple, provided there are no lookahead issues in recognizing the end of a group of records that constitutes a combined datum.

If you must look ahead, then you need some form of pushback as well. This means either A or B must have private memory to the tune of one input record, plus state information, to assist the input parse. So once again B is the least complex if it is the main function.

You should not be surprised to learn that all modules are least complex when implemented as main functions. That is one of the reasons UNIX-style pipelines are often so cheap to code and maintain. Each module is the boss of its own little data transformation, and the operating system solves most of the coordination problems in a standard way. But if you're determined to implement a data flow diagram as a single hierarchy of modules (a single program), then only one module can be the boss.

That's not as bad as it sounds. As this little example shows, B is almost as simple as an input module. And it is not too bad as an output module. Chances are the other modules in the data flow diagram have different problems. You should be able to guess the properties of a module that unpacks records, for instance, rather than packing them as B does.

An unpacker has private memory as an input module, is simple as a main function, and is equally simple as an output module. None of the implementations are very difficult to write or maintain.

So the seat-of-the-pants rule for picking the best bubble to grab is really quite straightforward: locate the one that has the most complex structure and make it the boss. Chances are that one module stands out from the others in this regard. And the others can probably be implemented reasonably well wherever they fall on the hierarchy.

You will find that this straightforward rule usually selects modules somewhere near the center of a data flow diagram. The fringe modules are usually the easiest to simplify by outside-in design, so they present the fewest problems by the time you get to top-down design.

The approach outlined in this column and my previous column covers several major schools of software design. Each uses a different vocabulary and devotes considerable attention to details I have touched upon fleetingly here. I will spell out the parallels in approaches between schools, and some other details, in my next column.

P.J. Plauger has coauthored several popular textbooks with Brian Kernighan, including The Elements of Programming Style *and* Software Tools in Pascal. *He is secretary of X3J11, the ANSI C standard committee, and convenor of the ISO C standard committee. He is also the president of Whitesmiths Ltd.*

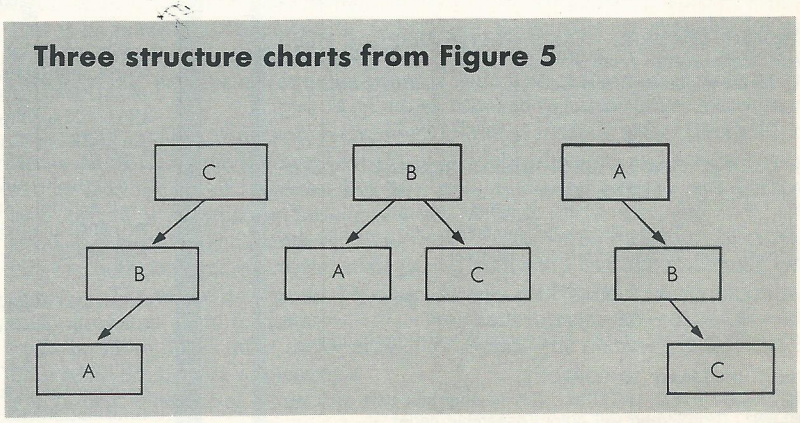

Figure 6.

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CIRCLE 15 ON READER SERVICE CARD

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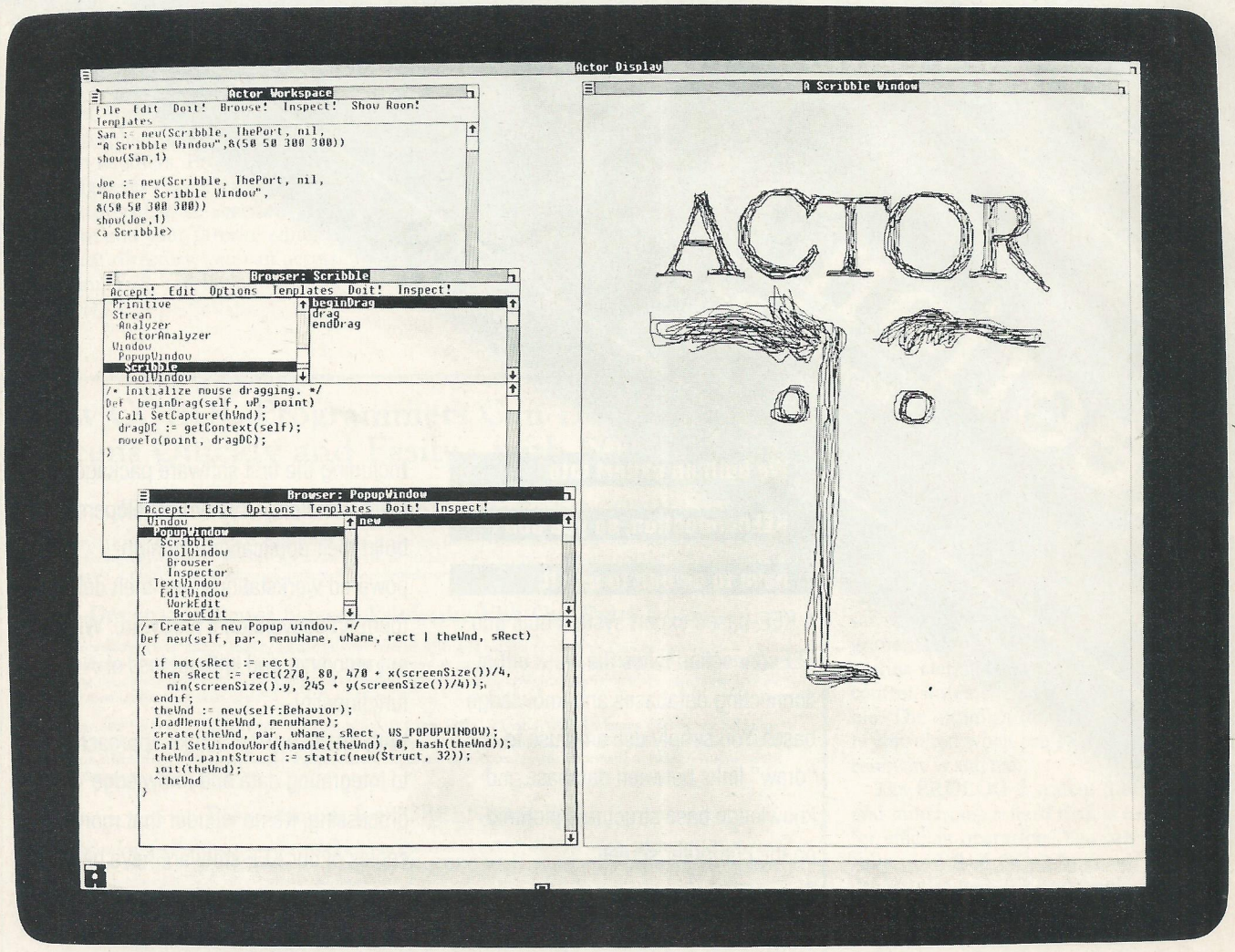

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CIRCLE 16 ON READER SERVICE CARD

80386 promises a new age for AI

By Susan J. Shepard

The Intel 80386 microprocessor is here—at last. It is proving to be all that we expected, and the last obstacle to 386 supermicrocomputers is an operating system that can avail the developer and user of its power. It will provide a powerful and affordable platform for expert systems and other AI applications that are truly useful.

AI has been been waiting for this chip; many AI applications developers whispering, "When the 386 is available...." and hinting of powerful systems for the desktop and a rich development environment for the programmer working and learning in the real world.

The Intelligent Computer Systems Research Institute at the University of Miami, Coral Gables, Fla., predicts a threefold increase in expert systems this year, largely because the 80386 has arrived. In fact, the processor narrows the gap between micros and LISP workstations significantly—at a substantial dollar difference.

What will micro-based 386 systems offer when an adequate operating system is available for the industry-standard MS-DOS compatibles? What do available 386 systems offer for AI development? Pending a widely available operating system with downward compatibility to prior MS-DOS software, AI tools implemented for that environment will have to run on 386 machines within the constraints of DOS and 16 bits. Is it worth moving up to 386 running under DOS now?

Each of these questions is complex, and many factors must be weighed to ensure that time and money are invested wisely now and prior hardware and software investments are protected. We can start by looking at the 80386 itself and then consider the Inboard 386/AT system, selected for best price, best performance, and compatibility, to see how it handles some basic AI tools for micro development.

We'll also look briefly at Gold Hill's 386-based LISP development system built to deliver an optimized hardware and software environment to existing IBM XT/AT compatibles.

Intel's 80386

Intel's 80386 is a high-performance, 32-bit microprocessor designed for computer-intensive applications such as CAD/CAM, high-resolution graphics, high-level factory and office automation, and publishing. More importantly, it will permit advanced systems generally termed AI to move toward production applications levels. Machine vision, speech recognition systems, and more complex expert systems will become more feasible and affordable. The 32-bit 386 integers and 80-bit 80287/80387 floating point numbers can easily support the speed and accuracy of computation required for fine precision and axis control of an industrial robot.

Frequencies of 12 MHz and 16 MHz are now available, and a 20-25 MHz frequency is forthcoming. The 16 MHz, running without wait states, can achieve a sustained 3 to 4 millions of instructions per second (MIPS). In addition to faster clock speeds, the 16 MHz version has lower clock counts.

This architecture has the programming resources required to directly support applications characterized by large integers, large data structures, and large programs or large numbers of programs. Physical address space is 4 gigabytes; logical address space is 64 terabytes. Eight 32-bit general registers can be used interchangeably as instruction operands and addressing mode variables. It has a complete instruction set for manipulating data types and controlling execution. Data types include 8-, 16-, and 32-bit integers and ordinals, packed and unpacked decimals, pointers, and strings of bits, bytes, words, and double words.

At this speed, memory access is obviously a potentially serious problem. The 80386 bus is designed to use both 45 nanosecond static RAM (SRAM) and slower, less expensive 100ns-120ns dynamic RAM (DRAM) chips. Zero wait state caches are supported, and their size can be anywhere from the useful minimum 4K to the entire physical address space.

Other features are virtual memory support, configurable protection, new debug registers, and object code compatibility. The 80386 has four modes: real, virtual 8086, protected, and native 80386. Real mode is entered after reset; it is essentially a very fast 8086 mode. Virtual 8086 uses special flags, registers, and interrupts to permit fast, safe multitasking in environments that extend the concept of virtual memory in individual programs to include an entire PC.

Protected mode emulates the 80286; at this time neither the 80286 nor 80386 using MS-DOS can take advantage of the protected mode, with the exception of specialized software such as Gold Hill's GCLISP 286 and 386 Developer packages or Texas Instrument's PC Scheme and Personal Consultant PLUS. Native 80386 permits operating systems and programs up to 4 gigabytes of RAM and can address 64 terabytes of virtual memory.

Virtual memory enables the maximum size of a program or programs to be determined by available disk space rather than RAM. AI applications are typically memory intensive, and virtual memory means more flexible delivery of higher performance software on less expensive hardware. Programmers can leave storage management to the operating system rather than writing overlays, to an extent that is not yet clear.

For example, how much real memory is needed to support a certain amount of virtual memory? B.E. Smith and M.T. Johnson, in *Programming the Intel 80386*, estimate that about twice as much virtual memory as real memory can be supported.

The 80386 provides a range of protection facilities that can be applied selectively as the application warrants: separation of task address spaces, from 0 to 4 privilege levels, typed segments, access rights for segments and pages, and segment limit checking. Protection checks are performed in the on-chip pipeline to maximize performance. These facilities are particularly useful when developing programs the size the 80386 is

built to handle—hundreds or thousands of modules.

Four on-chip debug registers enable code or data break points. The registers are independent of the protection system and can be used by all applications. Conventional debugging through a break point instruction and single stepping are supported as well.

Object-code-level compatibility with both the 80286 and 8086/88 processors protects existing software investments and allows rapid development for the 80386. 80286 and 80386 programs can run concurrently. The 80286's architecture is a proper subset of the 80386's, so existing 80286 operating systems and applications can be ported without change.

Virtual 86 is a compatibility feature that establishes a protected 8086/88 environment within the 80386's protected multitasking environment. 80386 paging can give each Virtual 86 task a 1 MB address space anywhere in the physical address space and an 8086 environment. It is possible to build systems that could execute 80386, 80286, and 8086/88 software concurrently. 8086 software can run in the real mode of the 80386, but timing-dependent programs may need modification to function properly in the much faster mode.

Hands on

The Intel Inboard 386/AT add-in 80386 system with 80287 or 80387 for the IBM AT and close compatibles offers a reasonably priced, high-performance entry to 80386-based micros. We will look closely at that product, and run some AI applications on it (Tables 1-4), as a way

Benchmarks for PC Scheme (sec)

Test	80286 640K	80286 2 MB	80386 640K	80386 2 MB
Prime Sieve	16.70	30.71	8.85	15.49
Fib(60) (iterative)	.06	.06	−.01	−.01
Fib(60) (floating point)	.38	.44	.11	.11
TAK	16.02	35.59	8.12	9.0
DERIV	81.40	134.51	48.71	78.98
DDERIV	103.21	167.58	51.85	100.95
DIV2 (iterative)	21.42	34.16	9.06	16.04
DIV2 (recursive)	62.62	109.57	27.35	40.75
Factorial (100)	.11	.17	.11	.11

Results are for PC Scheme on 80286/8MHz and 80386/16 MHz.
Conventional (640K) and extended memory (2MB) mode Scheme used for each processor.
No software or hardware was changed except for Inboard 386/AT.
No math coprocessor installed in either configuration.

Table 1.

GCLISP benchmarks (sec)

Test	80286	80386
TAK	57.39	32.29
DIV2 (iterative)	78.05	56.95
DIV2 (recursive)	98.30	67.39
DERIV	111.43	58.38
DDERIV	129.19	100.03

Results are for GCLISP v. 1.01 interpreter.
Tests run in conventional (640K) memory for each configuration. GCLISP does not support bignums.

Table 2.

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XTC was originally written for a Compupro 8086 machine running CP/M-86, for use in robotic software development. It was called GLACIER, an acronym for "Good Lord, A Centralized Interactive Editing Routine". GLACIER had multiple windows and the ability to share text between windows, and a set of editing commands which were based on the most popular word processor at that time —Wordstar. Windows were important because it was necessary to view several different text files or several different parts of the same text file without constantly switching back and forth between them. Originally written in Pascal MT+86, GLACIER was rewritten for the IBM PC family in IBM Pascal. Blocks, text buffers, and a macro programming language were added to the new editor, and it was released as XTC version 1.2.

Now, nearly three years later, XTC 3.0 is a complete text editing environment with over 100 commands in seven categories: File Interface, Windows, Blocks, Text Processing, Editor Programming, Multitasking, and Special Editing. It comes with its source code on disk, and a full-size, laser-typeset, 180+ page manual. Unlike other programmer's editors, XTC is user-modifiable at the source code level, so you can add to XTC's basic command set, or change how the commands work entirely.

How XTC works

The editor's design was based on its ability to share text across windows and buffers (which are just windows that don't get displayed). Pascal's strong typing lead to the storage of text in a doubly-linked list of line buffers (hereafter called a "*text stream*"), so that cursor movement commands could move a "current pointer" around the text with simple pointer assignment operations. This also makes insertion of text very efficient, since it can be accomplished with one short memory move to make room for a new character.

XTC keeps track of a doubly-linked list of data structures called *window descriptors* which describe the windows displayed on the screen. There is also another doubly-linked list of window structures which are not displayed by the display algorithm for XTC's buffers. Each window descriptor contains information about the physical coordinates of the window on the screen, how big the window is, a pointer to a text stream where the window is positioned over, and a pointer to the current cursor position within the window. Other information, such as the current filename and options like wordwrap and autoindent are also saved in the window descriptor. Figure 1 shows how XTC's principal data structures are connected.

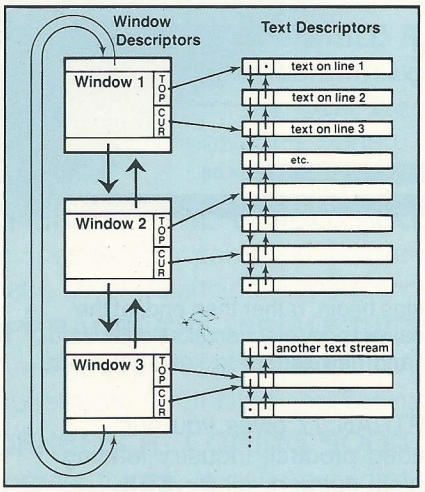

Figure 1. XTC's text and window management data structures. Here two windows share a text stream, and a third is positioned over a different stream.

How to use XTC

Knowing about how a program works makes it possible for you to use it in the best way possible. Obviously, XTC's data structures make for very fast zooming through a text stream, and insertion. It also makes it easy to make new windows quickly and either share text among them or look at other files while you concentrate on the main task of creative development.

There is no free lunch, unless you learn the system.

It takes XTC longer to read a file into data structures, and allocate memory for data structures on the fly for each line descriptor than it does for an unstructured editor to read text into big block buffers. Therefore, programs developed under XTC tend to be composed of a main file and many *include* files. XTC's main draw then, is its windowing system which makes you actually want to put a separate C function in a different *include* file. By storing each function in a separate file, XTC lets the operating system manage your library of source, and it becomes easy to share source routines among several software products.

This system works very well. We've used it in the design of our latest operating system, Wendin-DOS. The new operating system is composed of over 32 modules written in C and assembly language, and each module source file (named *modulename.C*) uses *include* statements to draw in header files that describe data structures, and function files (named *functionname.I*). Altogether, XTC and the operating system manage over 50,000 lines of source code in 500 different source files. The simple convention of using a function's name for its source file makes it easy to retrieve the exact piece of code you're interested in, without wading through tons of code in a single big source file.

Next month, we'll present XTC's programming commands and macro languages. If you don't already have XTC, get your copy and follow along. You simply won't get the chance to do that with any other editor.

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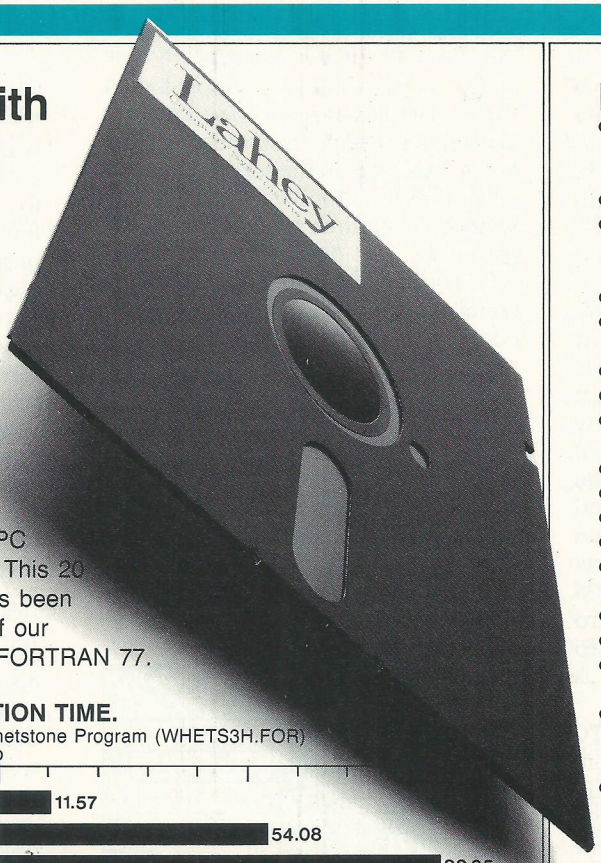

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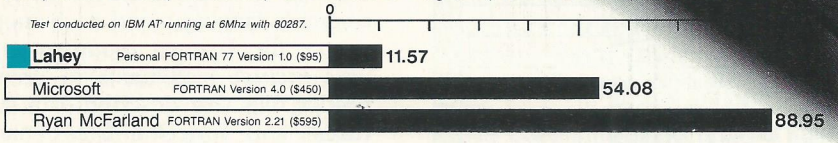

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CIRCLE 18 ON READER SERVICE CARD

It is possible to build systems that could execute 80386, 80286, and 8086/88 software concurrently

of indicating the tremendous improvement in an AI development project using the 80386.

Other products giving good performance are, of course, the Compaq 386 series of personal computers and the Gold Hill 386 LISP System. The latter is an add-in board for the IBM PC XT or AT with a sophisticated LISP development software package.

Because these systems are based on the 80386, my earlier discussion applies to each of them, with the exception of SRAM caching and 80387 support. Cache implementations are very important for achieving good performance, and different approaches should be evaluated before purchase. Vendors should be well-queried about performance and compatibility for your needs.

The marketplace for 80386-based AI is changing rapidly. Joining Gold Hill in the race to exploit the chip's power—with or without an operating system—other major vendors are making announcements. Lucid Corp., which offers AI tools for workstations, IBM PC RT, and other large systems, is developing a package that will run under UNIX on the 80386. Because UNIX is widely used on workstations, ports will increase for both the operating system and product.

My evaluation of the options led me to choose the Inboard as the best solution for my needs, offering compatibility both with present software and future expan-

Various performance considerations (sec)

Task	80286/8MHz	80386/16MHz
Norton SI	7.7	18.7
Load:		
GCLISP 1.01	16.53	6.47
PC Scheme ext.	10.49	5.22
PC Scheme conv.	8.20	4.13
Personal Consultant PLUS ext.	26.40	15.31
PC+ 360K KB	15.21	7.43
Kedit and 16K file	5.99	3.10

Table 3.

Inboard 80386/AT with 80387 coprocessor (sec)

System/ using	Whetstone[1]	Dhrystone[2]	TAK[3]	DDERIV[3]	IDIV2[3]	FIB(60) (f-p)
Inboard	395,000	2,083	8.13	42.40	9.01	.09
Compaq386	175,000	3,333	N/A	N/A	N/A	N/A
SUN-3/T language	N/A	N/A	0.25	4.92	0.24	N/A
SUN 2/120	N/A	806	N/A	N/A	N/A	N/A
80286 3000HL	N/A	1,041	16.02	103.21	21.42	.38

1. Curnow, H.J. and B.A. Wichmann: *Computer Journal.* vol. 19, no. 1.
2. Weicker, R.P.: *Communications of the ACM.* vol. 27, no. 1.
3. Gabriel, R.P.: *Performance and Evaluation of LISP Systems.* MIT Press, 1985.
N/A = Not available.

Inboard 80386/AT runs at 16 MHz. 80387 coprocessor runs at 16 MHz. MS-DOS 3.2. Gabriel benchmarks run with Texas Instruments PC Scheme v. 2.0 in conventional memory mode. Performance of other systems offered for general comparison only.

Table 4.

Dbase*

programming tools
*Clipper, FoxBASE+,
dBASE, QuickSilver

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UI is a second generation, programmable product — so your code comes out your way. Application specific edits, for instance, can be placed in the UI 'template' which controls the generation. Edit the screen appearance until it 'looks and feels' perfect. Everytime you generate code, your special logic is preserved.

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sions. Its performance for the languages and tools I use, and its overall system improvement, has exceeded Intel's claims for the board. I found that I not only realized a two- to three-fold increase in execution times for software at 16 MHz, but I also got better performance indexes from a rather old Seagate ST-225 hard disk using the CORE disk performance test v. 2.7. This was a pleasant surprise, but replacing the disk with a faster unit would improve performance tremendously.

Specifications for the board are: speed selection ranging from 16 MHz to the original system speed; 256K x 32-bits memory size; 120ns DRAMs up to 3 MB of 32-bit memory and access to other extended or expanded memory in the host system; and a direct-mapped 45 nanosecond SRAM cache, 64K x 32 bits. Intel claims that 90% of the 80386's memory requests are filled from this 64K cache instead of the older, slower system memory.

Overall performance indicates that hits are at least 90% when memory outside the zero wait-state cache must be accessed and wait states are introduced. However, since these are lower clock count 80386 waits, the effect is not as severe as on the 80286.

The board uses a 16-bit slot in the host machine. The 80286 chip is replaced by an ingenious cabling technique from the system board CPU socket to the 80386 board. Control software bridges differences in 80386 and 80286 error handling and offers other easy-to-manage drivers. Speed is software-switched.

The move from 8 MHz to 16 MHz has caused no compatibility problems with any of the current AI language implementations or expert system tools for MS-DOS, with the exception of the Gold Hill GCLISP 286 Developer. This product will not run on the Inboard, but the 386 Developer will run on the Compaq 386 and Gold Hill's Hummingboard.

Compatibility with the Inboard could not be tested. Because the performance of these individual applications varies widely, the impact of the 80386 can best be described as a big improvement. Waits for notoriously processor-intensive LISP interpreters are reduced anywhere from 25% to 75%. Shells improve in a similar fashion.

The benchmarks for extended memory PC Scheme (Table 1) make that package's 2 MB memory capability attractive. Gold Hill's GCLISP interpreter (Table 2) improves significantly as well.

The improvement in 80286 or 8086/88 AI tools is significant without even attempting to optimize code for the environment. The 80386 architecture offers a great opportunity for AI. Very soon, AI tools that can exploit this architecture will join Gold Hill's package, and applied AI may finally emerge as a major element in practical computing.

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Abelson, H., and G.J. Sussman. *Structure and Interpretation of Computer Programs.* The MIT Press, 1985.

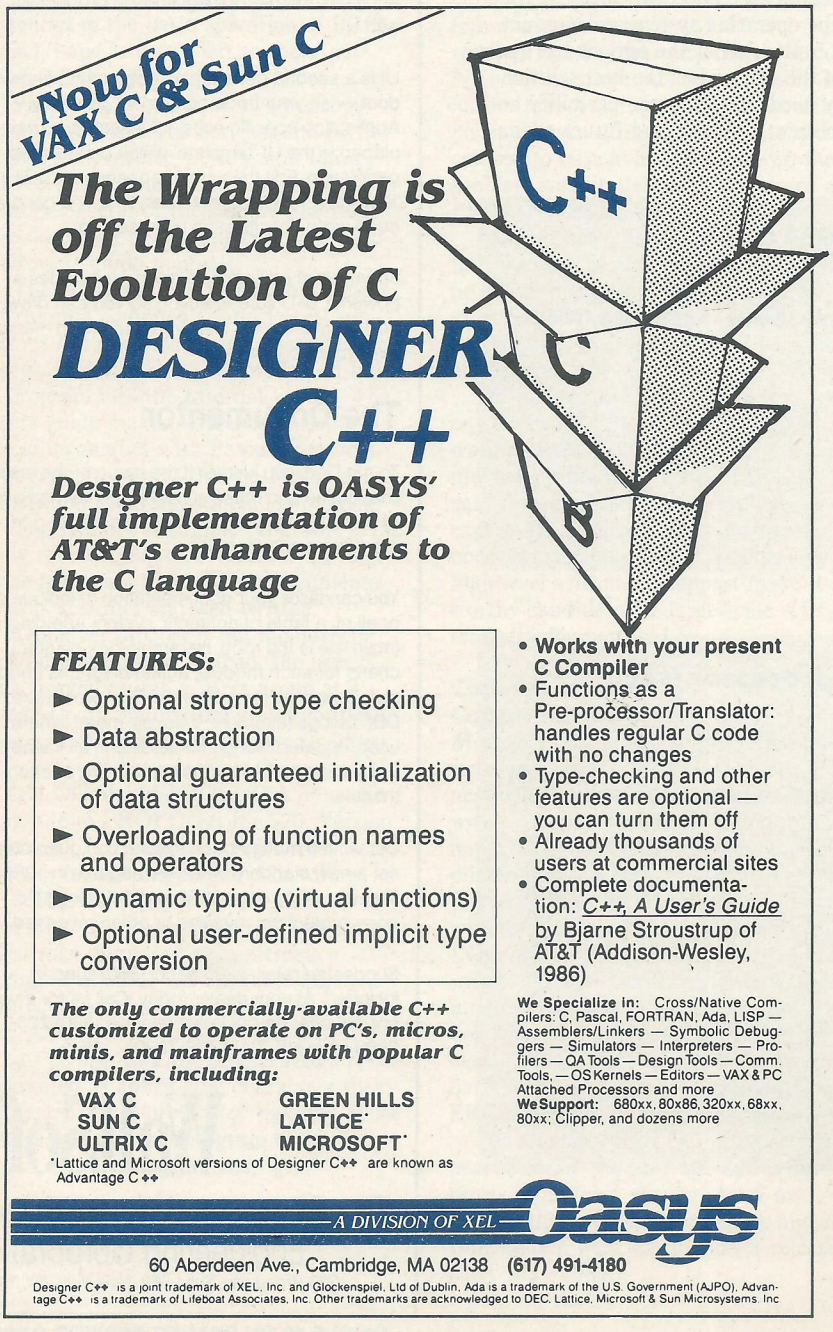
Gabriel, R.P. *Performance and Evaluation of LISP Systems.* The MIT Press, 1985.

Introduction to the 80386. Intel Corp., 1986.

Smith, B.E., and M.T. Johnson. *Programming the Intel 80386.* Scott, Foresman and Co., 1987.

Source code for the benchmarks is available on the COMPUTER LANGUAGE *Bulletin Board Service and CompuServe forum.*

Susan Shepard is a writer and editor specializing in the microcomputer field. She is the AI Insider columnist for AI EXPERT. *In addition to doing private consulting, she is a program consultant for the Academy for Educational Development, an international consulting firm based in New York, N.Y.*



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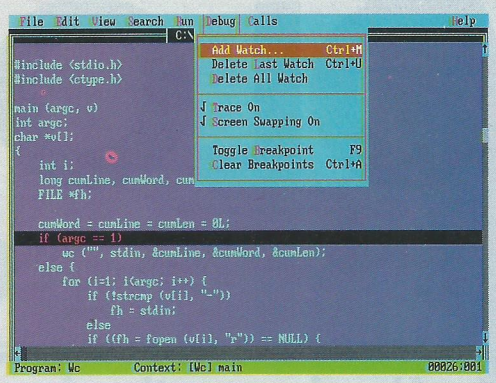

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PROLOG and C

AI and conventional languages don't have to be at odds—they can complement each other's strengths

By M. Haytham Matthews

The recent proliferation of computer languages presents an interesting challenge to software developers. Given that each language—or, more precisely, each implementation—has its own share of strengths and shortcomings, making the best choice can be something of a dilemma.

Information Resource Management Associates was recently involved in an effort to take an application developed on a LISP machine and reimplement it on a PC/AT. The experience gave rise to issues germane to the selection of an implementation language as well as to the nature of multilanguage programming in PROLOG and C.

The application in question required some data base functionality (provisions for adding, editing, and deleting data) as well as an inferencing component. The inferencing had to be done in real time, and the data had to be easily accessible and sorted in different but predictable ways.

In addition, the interface could not be an exact replica of the application interface on the LISP machine because of differing screen characteristics (smaller dimensions, etc., on the PC/AT). But it had to be clear, consistent, and very easy to use. Furthermore, since changes to the design of the application appeared likely en route to the delivery system, flexibility was at a premium.

Choosing a base language

The criteria used to choose an implementation language were based on the assumption that the PC/AT prototype would serve as a feasibility analysis and would later need to be rewritten in a suitable delivery language. (The prototype has since been judged sufficiently robust to move directly into the delivery environment on a trial basis.)

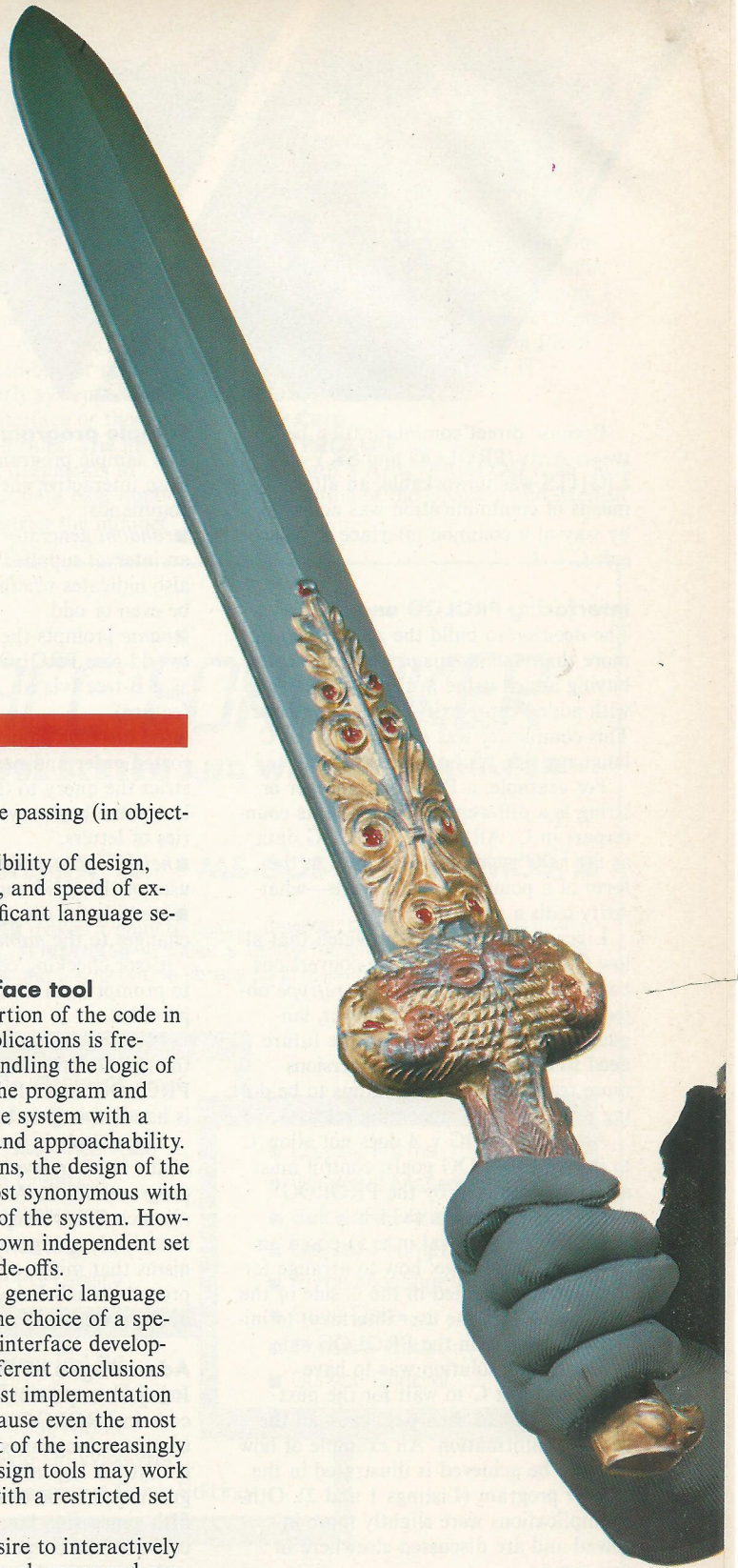
The ideal language on which to base such a prototype would have been the same one that supported the program on the LISP machine. As that language was unavailable for PC/AT-class machines, PROLOG was selected as an appropriate alternative.

PROLOG is a fifth generation language that is more widely known and arguably more stable in its structure than many of the artificial intelligence languages and tools on the market. In the terminology of expert systems, it is a backward-chaining symbolic language with a built-in, depth-first search control regime based on unification and Horn logic.

PROLOG is relational in the sense of relational data base languages such as IBM's SQL. However, it is much more than a data base language, having been used extensively for AI and expert systems applications.

Nevertheless, integrated data base features figured highly in our decision to use PROLOG. The extent of data base functionality is one area that distinguishes one PROLOG implementation from another.

Join Forces



In our case, Arity Corp.'s Arity/PROLOG v. 4 was a good choice, partly because of its built-in facilities for handling B-trees and hash tables. Another factor was the availability of a compiler for Arity/PROLOG (PROLOG is commonly an interpreted language). Thus if the language was as well suited to the problem as we thought, we would be giving the possibility of real-time inferencing a reasonable shot.

Another option was to use a conventional language like Pascal or C. Even with a compiler, fifth generation languages running on standard hardware generally cannot rival more conventional ones in execution speed. But this is partly a consequence of a trade-off between power of expression and run-time performance.

Fifth generation languages are valuable in large measure because they help reduce the cognitive distance between the verbal description of a process or solution and its representation in executable code. The concepts and logic that constitute the design of a program are expressed more directly in such a language and are less burdened by nonmeaningful declarations and restrictive syntactic requirements. The resulting programs are thus easier to both read and change. However, this clarity and malleability is paid for at run time.

Among the features that help increase the cogency of fifth generation language programs, at the expense of execution speed, are the dynamic binding of variables and types, automatic memory management, and message passing (in object-oriented languages).

In our project, flexibility of design, speed of development, and speed of execution were all significant language selection criteria.

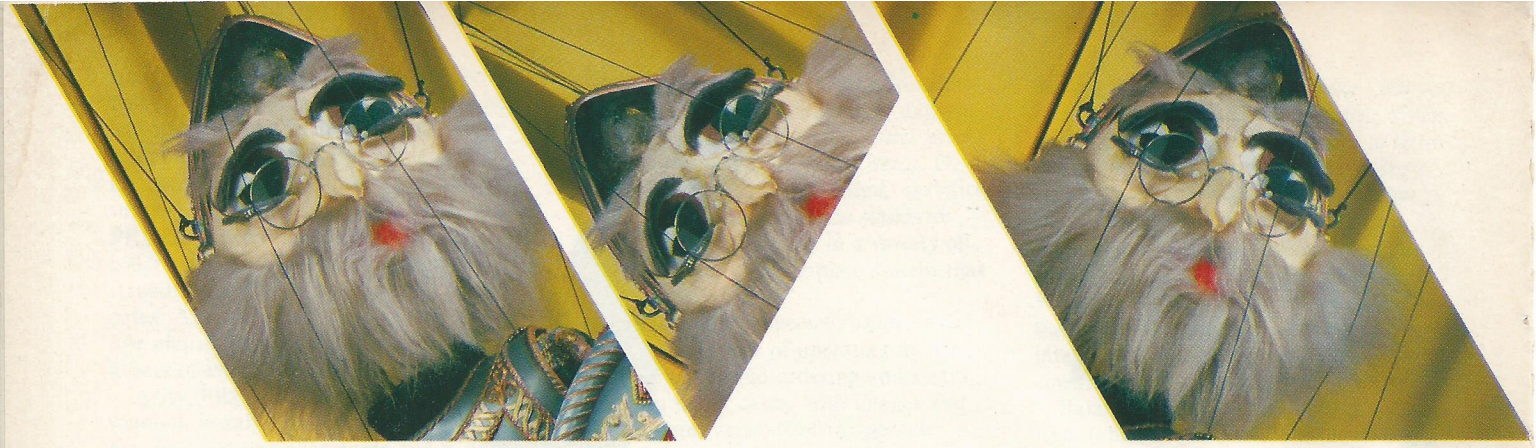
Choosing an interface tool

A considerable proportion of the code in end-user-oriented applications is frequently devoted to handling the logic of interaction between the program and user and endowing the system with a sense of smoothness and approachability.

In many applications, the design of the user interface is almost synonymous with the high-level design of the system. However, it also poses its own independent set of challenges and trade-offs.

Applying the same generic language selection criteria to the choice of a specialized tool for user interface development may lead to different conclusions about which is the best implementation language. This is because even the most language-independent of the increasingly powerful interface design tools may work (or work well) only with a restricted set of languages.

In our case, the desire to interactively design screens with touch zones and pop-up windows leads to the selection of a product called SKYLIGHTS, produced by Skylights Software. (For a review of this product, see "Program prototypers and the illusion of reality," *COMPUTER LANGUAGE,* Jun. 1987, pp. 109-112.)



Because direct communication between Arity/PROLOG and SKYLIGHTS was unworkable, an alternative means of communication was achieved by way of a common interface to Microsoft C v. 3.

Interfacing PROLOG and C

The decision to build the application in more than one language was, in effect, buying added value in the user interface with added complexity in program code. This complexity was felt most in the C language side of the application.

For example, a PROLOG integer or string is a different animal than its counterpart in C. All Arity/PROLOG data, as far as C is concerned, comes in the form of a pointer to a structure—what Arity calls a *reftype*.

Library functions are provided that allow C code to perform type conversions back and forth between these *reftype* objects and C data types. However, language interface designers of the future need to make these type conversions more transparent (Arity claims to be doing just that in its upcoming release).

Arity/PROLOG v. 4 does not allow C to invoke PROLOG goals; control must always be retained by the PROLOG code. This restriction (which is also scheduled for removal in v. 5) posed an interesting challenge: how to arrange for user actions detected in the C side of the application (via the user interface) to initiate processing in the PROLOG side.

The simple solution was to have PROLOG ask C to wait for the next user request and then pass back all the relevant information. An example of how this can be achieved is illustrated in the sample program (Listings 1 and 2). Other implications were slightly more involved and are discussed elsewhere in this article.

One stylistic point that deserves special mention is the use of dispatch procedures and functions to encapsulate the communication channel between the two languages. This approach, along with mnemonic and other conventions, pays off in debugging and maintenance.

Sample program description

The sample program in Listings 1 and 2 is an interactive shell that accepts five commands:

- *random* generates a random number in an interval supplied by the user. The user also indicates whether the number should be even or odd.
- *name* prompts the user for a new name to add to a PROLOG data base stored as a B-tree (via an Arity built-in feature).
- *list* displays names in the data base in sorted order and permits the user to restrict the query to those names where the last name begins with a user-supplied series of letters.
- *help* displays a message informing the user of the valid commands.
- *bye* bids the user good-bye and saves all changes to the *nametree* data base.

Error checking consists of continuing to prompt until a valid response is provided.

Most of the logic and functionality in the sample program is handled by the PROLOG code. The user interface I/O is handled largely by the C code.

The sample is meant to illustrate some of the issues relevant to two-language programming in Arity/PROLOG and C. As such, I have kept away from using complex language constructs and mechanisms that might otherwise have improved the efficiency or generalizability of the code.

Advantages of PROLOG

It is just as possible to write inscrutable code in PROLOG as it is in most other computer languages. My claim, however, is that the logical foundations of a program tend to be closer to the surface in fifth generation languages than in more conventional ones.

As an example, even though the reader may not have extensive knowledge of the PROLOG language, many of the basic ideas and definitions that make up the sample PROLOG program (Listing 1) can be surmised with a bit of persistent study.

The smooth integration of data base functionality with the PROLOG code is another important feature of PROLOG implementations like Arity's. This integration can be very useful in prototyping decision support systems as well as creating stand-alone applications that require flexible but limited data base support. (PROLOG implementations by themselves have yet to support data base functionality at the same level as separate data base products.)

The sample program contains an example of the use of a B-tree for storing full names sorted by last name followed by first and middle names.

An interesting aspect of the PROLOG language is the ease with which additional features can be added to procedures through the addition of rules. The procedure *inbetween* in the sample program, for example, is able to serve a dual purpose. If the first argument is an instantiated variable (if it has a value), it will perform a test to determine if that value lies in the interval defined by the second two arguments. Alternatively, if the first argument does not contain a value, it will be instantiated to a random number within the interval bound by the second two arguments.

Many features of the PROLOG language make it a potentially useful tool for prototyping. It is also useful for application development in situations where flexibility is more important than speed.

However, much depends on the quality of the PROLOG implementation and, in particular, on the extent of the built-in features analogous to library functions in languages such as C.

Advantages of C

The C language is distinguished by speed and conciseness as well as flexibility. But whereas PROLOG supports conceptual flexibility in the sense of readability and ease of modification, C supports flexibility in the sense of getting the most out of the machine.

This kind of flexibility and speed has made C a good language for developing user interface tools that directly manipulate the video buffer, etc. Interfacing to C means gaining access to such tools as well as to the extensive library functions developed for C.

The sample program in Listing 2 pro-

vides two examples of C functionality that would have been unavailable had the program been written exclusively in PROLOG.

The *printf* and *scanf* statements present in all commercial C compilers provide for several I/O formatting features generally unavailable in the basic PROLOG product. This functionality is used to format the output generated by the *list* command in the sample program.

The random number generator provided by Microsoft C was also used instead of the one available in Arity/PROLOG because an integer value was desired. Arity's generator returns a real number between 0 and 1.

Interface restrictions

Apart from declaration requirements and the type conversions mentioned earlier,

PROLOG terminology

The smallest meaningful program units in PROLOG are numbers and atoms. An atom is a word beginning with a lowercase letter. All words beginning with uppercase letters are treated as variables, which may hold atoms, numbers, or larger constructs.

PROLOG, like LISP, is not a strongly typed language, although the type of a value can generally be determined and used in a PROLOG rule. Variables that have values are referred to as being instantiated.

A PROLOG structure consists of a functor and a parenthesized series of comma-separated arguments, as in *has(Person,Thing)* or *ishuman-(ronald)*. These constructs are best thought of as denoting relationships.

The fundamental data structure of PROLOG is the term, which encompasses atoms, variables, and structures alike. Depending on its position in a PROLOG program, a term is interpreted as either a piece of data, statement of truth, or goal or query to be deduced.

In pure PROLOG, there is no distinction between a piece of data and a statement of truth. However, PROLOG implementations such as Arity Corp.'s permit the programmer to make a distinction to gain data base efficiency and functionalities.

Terms that do not involve variables (such as *ishuman(ronald)*) are called ground. When PROLOG execution finds a nonground goal, it tries to reduce it to a ground instance of that goal by finding a consistent substitution for the variables in the goal's arguments.

For example, the goal *max(X,Y,X)* might succeed with the substitution, $X=10$ and $Y=5$, yielding *max(10,5,10)*. *max(5,10,10)* would be inconsistent in trying to match X simultaneously to both 5 and 10.

A PROLOG program consists of a set of rules for deducing the truth of a given goal from a conjunction of other goals. These rules (clauses) are of the general form:

```
goal1 :- goal2, goal3, ..., goalN
```

Such a rule would be read as "*goal1* is true (successful) if *goal2* can be established, *goal3* can be established, ..., and *goalN* can be established such that all variable substitutions (within and between goals) are consistent."

In this example, *goal1* is said to be the head of the rule and the conjunction of goals, and *goal2, goal3, ...* is said to be the body.

A set of rules with the same head represents alternative ways of establishing the same goal. Such a set is sometimes called a procedure. An example of a procedure consisting of two rules is:

```
max(X,Y,X) :- number(X), number(Y),
  X >= Y
max(X,Y,Y) :- number(X), number(Y),
  Y > X
```

Note that a head is part of the same procedure as another head if they have the same functor and number of arguments. The number of arguments of a term is called the arity of that term.

PROLOG procedures are somewhat analogous to procedures in mainstream languages and are conceptually like *CASE* (or switch) statements (the rules being analogous to branches). The goals in the body of a procedure are invoked sequentially, and a procedure is exited when all goals in one of its rules have succeeded.

However, a fundamental difference in the flow of control arises when one of the goals fails. Whereas in mainstream languages failed statements must be handled explicitly, PROLOG automatically backs up to the previous goal, attempting to satisfy it in a different way. This behavior is known as backtracking and is key to understanding the language.

The cut operator—an exclamation point (!)—is a controversial and important topic in practical applications of the PROLOG language. Its effect is to inhibit backtracking. When placed between two goals in the body of a rule, the cut operator will prevent execution from reattempting the first goal when the second one fails. Instead, the entire procedure will fail.

While overuse of this construct can have insidious results, judicious application of the cut can dramatically increase a program's storage and runtime efficiency.

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two restrictions imposed by Arity's PROLOG-to-C interface necessitated accommodations in the structure of our sample program.

The first was that C could not invoke PROLOG. The main implication of this for the PROLOG side was that all information regarding interaction with the user had to be passed back to PROLOG through preestablished functions before some actions could be taken.

For example, the C functions, not being able to access the PROLOG data base directly, could not directly invoke a PROLOG procedure to return a list of names. If for some reason C needs to retain data in between communication events with PROLOG, local variables cannot be used since the function must exit before communication can take place.

The implementation of the *list* command was designed to illustrate how C could retain data in this way by using a dynamically allocated buffer. This strategy can be further generalized by using an array of such buffers.

The second restriction has to do with the behavior of C functions during backtracking. As noted earlier, when a PROLOG goal fails, previously encountered goals are reinvoked in an attempt to find a different way to satisfy them. If successful, this process of reentering goals often results in a different instantiation of the arguments to that goal.

Retrieving items from a data base is an example of a goal that typically succeeds during backtracking unless all items have already been tried. A goal that invokes a random-number generator should always succeed during backtracking since a new random number can always be generated.

An example of the use of backtracking is the second rule of the *even_or_odd_num_inbetween* procedure. The third goal in that rule invokes the *inbetween* procedure to generate a random number within the specified bounds. The last goal then tests that the resultant number is even or odd, as required by the instantiation of the *EvenOdd* argument.

If this test fails, execution will backtrack and reinvoke the third goal, resulting in the generation of a new random number, which is then tested, and so forth, until the test can be satisfied. (Note that while the use of backtracking here is largely for illustrative reasons, more complex tests could easily be substituted in place of even or odd.)

Arity's v. 4.0, however, does not support reinvocation of C goals. Instead, they simply fail automatically during backtracking. One method of working around this limitation is illustrated in the *found_random* rule used by *inbetween* to generate a random integer. (The procedure *prompt_for_bounds* is a good example also.)

In the definition of *found_random,* the C goal is preceded by a *repeat* goal, which is defined to always succeed. The effect is to reinvoke the C goal immediately after it is passed up during backtracking. This solution works, but it is inappropriate if the C goal can legitimately fail since such failure would cause an infinite loop.

An interesting exercise is to develop a more generic solution. One approch is to replace the *repeat* goal with a *repeat_unless,* which is designed to succeed during backtracking unless a termination symbol has been recorded in the PROLOG data base.

The C function then should be defined such that it invariably succeeds but has an extra parameter to serve as a flag, signalling when failure is intended. An *end_repeat* procedure must test this flag and, when indicated, fail in place of the C function—but not before recording the termination symbol in the data base so that *repeat_unless* can also fail.

The detailed requirements for interfacing Arity/PROLOG and Microsoft C are spelled out in the Arity Corp. booklet *Building Arity/PROLOG Applications.* Among other things, this publication goes into the requirements for compiling and linking.

My one observation about these requirements is that it pays to use a full-featured make utility (such as PS-MAKE, distributed by Unipress) and to save your make files for future reference.

Several additional files are available on the COMPUTER LANGUAGE *Bulletin Board Service and CompuServe forum.*

References

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Sterling, Leon, and Ehud Shapiro. *The Art of PROLOG: Advanced Programming Techniques.* Cambridge, Mass.: The MIT Press, 1986.

The Arity/PROLOG Programming Language and *Building Arity/PROLOG Applications,* Arity Corp., Concord, Mass., 1986.

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```
%              T H E    P R O L O G    M O D U L E              %

%   Arity requires that the certain procedures be declared     %
%   public and/or visible.  In addition, procedures may be     %
%   used from other files, so long as they are declared        %
%   "extrn" and linked in. The "extrn" declarations for        %
%   C functions also have a special format. The number         %
%   following each declaration is the arity of the procedure,  %
%   (the number of arguments it takes).                        %
:- public main/0.
:- visible main/0.

:- extrn c_dispatch_3/3:c('_c_dispatch_3').
:- extrn c_dispatch_2/2:c('_c_dispatch_2').
:- extrn c_init/0:c('_c_init').

%   A top-level procedure called "main" must be included in    %
%   compiled Arity PROLOG programs.  It is called auto-        %
%   matically when the program is started.  The following      %
%   "main" procedure contains an iterative loop that prompts   %
%   for a command and then causes an appropriate action to     %
%   be taken.                                                  %
main :-
        c_init,
        perform(help),
        repeat,
            performed_by_c(queryuser,Command),
            perform(Command),
        Command = = bye.

%   The dispatch procedures used here are imperative in        %
%   nature. The cut operator (!) is appended in the next       %
%   example to explicitly preclude any attempt to reenter      %
%   dispatch goals during backtracking.                        %
perform(A) :-
        dispatch(A),!.

performed_by_c(A,B,C) :-
        c_dispatch_3(A,B,C),!.

performed_by_c(A,B) :-
        c_dispatch_2(A,B),!.

%   dispatch is a procedure that responds to commands          %
%   received from the user.  The last clause serves as a       %
%   default action.                                            %
dispatch(Command) :-
        Command = = random,!,
        prompt_for_bounds(B1,B2),
        prompt_for_even_or_odd(EO),
        even_or_odd_num_inbetween(N,EO,B1,B2),
        performed_by_c(telluser,N).
dispatch(Command) :-
        Command = = name,!,
        new_name_is(First,Middle,Last),
        save_and_sort(First,Middle,Last).
dispatch(Command) :-
        Command = = list,!,
        lastname_starts_with(Prefix),
        list_names_starting_with(Prefix).
dispatch(Command) :-
        Command = = bye,!,
        save,
        performed_by_c(telluser,'Bye!').
dispatch(Command) :-
        Command = = help,!,
        performed_by_c(telluser,
              'COMMANDS:  name, list, random, bye, help.'),
        performed_by_c(telluser,
              'NAME:  add a new name to the database.'),
        performed_by_c(telluser,
              'LIST:  list names in the database.'),
        performed_by_c(telluser,
              'RANDOM: generate an even or odd random number.'),
        performed_by_c(telluser,
              'BYE:   save names to the database and quit.'),
        performed_by_c(telluser,
              'HELP:  display this message.').
```

Listing 1. *(Continued on following page)*

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```
dispatch(Default) :-
          performed_by_c(telluser,
                    'COMMANDS:  name, list, random, bye, help.').

%   prompt_for_bounds succeeds when the user enters two   %
%   positive numbers to be used as the bounds for         %
%   generating a random number.                           %
prompt_for_bounds(Bound1,Bound2) :-
          repeat,
            performed_by_c(promptforint,
       'Please give me an integer upper or lower bound: ',Bound1),
            performed_by_c(promptforint,
       'Please give me the other bound: ',Bound2),!.

% prompt_for_even_or_odd succeeds on user input of a 1    %
% (odd) or Ø (even)                                      %
prompt_for_even_or_odd(E) :-
          repeat,
                performed_by_c(promptforint,
                'Number should be odd (1) or even (Ø): ',E),
          (E = = Ø; E = = 1),!.       % semicolons are       %
                                      % interpreted as "or"  %

%   even_or_odd_num_inbetween succeeds by testing for or  %
%   generating an integer within the two (given) bounds   %
%   that is even if EvenOdd is Ø or odd if EvenOdd is 1.  %
%   It is interesting to generalize this procedure to     %
%   generate a number evenly divisible by an arbitrary    %
%   integer (not just 2)                                  %
even_or_odd_num_inbetween(SameNum,EvenOdd,SameNum,SameNum) :-
          (EvenOdd = = Ø; EvenOdd = = 1),
          EvenOdd is abs(SameNum) mod 2.
even_or_odd_num_inbetween(N,EvenOdd,Bound1,Bound2) :-
          (EvenOdd = = Ø; EvenOdd = = 1),
          ordered(Bound1,Bound2,LwrBound,UprBound),
          UprBound - LwrBound > Ø,
          inbetween(N,Bound1,Bound2),
          EvenOdd is abs(N) mod 2.

%   ordered unifies its second two arguments with its     %
%   first two. On success the second two arguments are    %
%   instantiated and in ascending order.                  %
ordered(N1,N2,N1,N2) :- N2 >= N1.
ordered(N1,N2,N2,N1) :- N2 < N1.

%   inbetween succeeds if its 1st argument is in the open %
%   interval defined by its 2nd two arguments or, failing %
%   that, by generating a random number and applying a    %
%   transformation to force it into the interval.         %
inbetween(N,Bound1,Bound2) :-
          nonvar(N),
          in_interval(N,Bound1,Bound2).
inbetween(N,Bound1,Bound2) :-
          var(N),
          found_random(Num),
          placed_between(Num,Bound1,Bound2,N).

%   placed_between applies a tranformation to its first   %
%   argument to generate a new number within the bounds   %
%   specified by its 2nd and 3rd arguments.               %
placed_between(N,Bound1,Bound2,Nplaced) :-
          ordered(Bound1,Bound2,LwrBound,UprBound),
          IntrvlSize is UprBound - LwrBound + 1,
          Nmod is N mod IntrvlSize,
          Nplaced is abs(Nmod) + LwrBound.

%   in_interval succeeds if its 1st argument is within    %
%   the open interval defined by its 2nd two arguments.   %
in_interval(N,Bound1,Bound2) :-
          ordered(Bound1,Bound2,LwrBound,UprBound),
          N >= LwrBound,
          N =< UprBound.
```

Listing 1. *(Continued on following page)*

```
%   found_random generates a random number.  So long as   %
%   its first argument is an uninstantiated variable,      %
%   it always succeeds.  repeat is used to simulate        %
%   reentering the C goal during backtracking.             %
found_random(N) :-
        var(N),
        repeat,
        performed_by_c(random,N).

new_name_is(First,Middle,Last) :-
        performed_by_c(promptfortext,'First name: ',First),
        performed_by_c(promptfortext,'Middle Name: ',Middle),
        performed_by_c(promptfortext,'Last name: ',Last).

%   save name in a b-tree sorted by lastname, firstname,   %
%   middlename                                             %
save_and_sort(FirstName,MiddleName,LastName) :-
      concat([LastName,FirstName,MiddleName],Sortkey),
      recordb(nametree,Sortkey,fullname(FirstName,MiddleName,LastName)).

lastname_starts_with(Letters) :-
     performed_by_c(promptfortext,
       'List names where last name starts with (* = anything): ',Letters).

% invoke any_more_names_to_output to display names in the  %
% data base. Succeeds by negating any_more_names_to_output %
% (the latter is guaranteed to fail).                      %
list_names_starting_with(Letters) :-
        Letters = = '*',!,
        not any_more_names_to_output.
list_names_starting_with(Letters) :-
        Letters \= '*',!,
        not any_more_names_to_output(Letters).

%   The rules below backtrack over the b-tree outputting   %
%   names to the screen.  They ultimately fail when no     %
%   more names remain to be displayed. The rule that       %
%   takes a Prefix argument also tests names, displaying   %
%   only those where the last name begins with the         %
%   letters in Prefix.                                     %
any_more_names_to_output :-
    retrieveb(nametree,SortKey,fullname(FirstName,MiddleName,LastName)),
    performed_by_c(holdthis,FirstName),
    performed_by_c(displayname,MiddleName,LastName),
    fail.

any_more_names_to_output(Prefix) :-
    retrieveb(nametree,SortKey,fullname(FirstName,MiddleName,LastName)),
       string_search(Prefix,LastName,Ø),
       performed_by_c(holdthis,FirstName),
       performed_by_c(displayname,MiddleName,LastName),
    fail.
```

Listing 1. *(Continued from preceding page)*

```
/*                    T H E    C    M O D U L E              */

/* These six header files are provided by the Microsoft C  */
/* compiler and contain declarations for C library         */
/* functions used in the program.                          */
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <ctype.h>
#include <malloc.h>
#include <limits.h>

/* The header file apctype.h provided by Arity contains
   declarations for "reftype" and for the Arity library
   functions that handle conversions between PROLOG and
   C data types.  SUCCESS and FAILURE are also defined
   as integer constants in apctype.h.  C functions invoked
   by PROLOG are only allowed to return one of these values.
   Other values must be passed back through the arguments
   in standard PROLOG fashion.                              */
```

Listing 2. *(Continued on following page)*

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```
#include "apctype.h"

#define YES 1
#define NO Ø

/* STREQ compares two strings for equality */
#define STREQ(a,b) (stramp(a,b)= =Ø)

static char Genbuf[1Ø24];    /* general-purpose buffer for */
                             /* transient storage          */

static struct BUFTYPE {       /* dynamically sized buffer       */
                char *buf;    /* whose storage space allocation */
                int bufinuse; /* and deallocation are handled   */
                } Hold;       /* by stash() and release()       */

int c_init()
{
     Hold.bufinuse = NO;
     return(SUCCESS);
}

/* These are the two dispatch functions that administer
commands received from PROLOG.  As a convention, the
number of arguments they take (their arity in PROLOG
terminology) is appended to the function names.          */
int c_dispatch_2(cmd,arg)
reftype cmd,arg;
{
     int length;
     char *command = Genbuf;

/* "findtype_c" is an Arity function that returns
an integer indicating the data type of its PROLOG
argument via defined constants (ATOM, etc.)     */
     if (findtype_c(cmd) != ATOM)
          return(FAILURE);

     gettxt_c(cmd,command,&length); /* "gettxt_c" converts a */
                                    /* PROLOG atom or string */
                                    /* to a C array of char. */
     if (STREQ(command,"queryuser"))
          return(query_user(arg));
     if (STREQ(command,"random"))
          return(random(arg));
     if (STREQ(command,"telluser"))
          return(telluser(arg));
     if (STREQ(command,"holdthis"))
          return(holdthis(arg));
     return(FAILURE);
}
int c_dispatch_3(cmd,arg,arg1)
reftype cmd,arg,arg1;
{
     int length;
     char *command = Genbuf;

     if (findtype_c(cmd) != ATOM)
          return(FAILURE);
     gettxt_c(cmd,command,&length);
     if (STREQ(command,"promptforint"))
          return(promptfor(INTEGER,arg,arg1));
     if (STREQ(command,"promptfortext"))
          return(promptfor(ATOM,arg,arg1));
     if (STREQ(command,"displayname"))
          return(displayname(arg,arg1));
     return(FAILURE);
}

/* Generate a random number and return it in PROLOG format.  */
int random(number)
reftype number;
{
     if (findtype_c(number) != UNDEF) /* UNDEF is a defined */
          return(FAILURE);       /* constant meaning an uninstantiated */
                                 /* (value-less) variable.  */
     putint_c(rand(),number); /* "putint_c" converts a C */
     return(SUCCESS);         /* integer to PROLOG */
}
```

Listing 2. *(Continued on following page)*

```
/* "telluser" displays its argument to the terminal screen. */
int telluser(arg)
reftype arg;
{
     int number_of_chars, num;

     switch (findtype_c(arg)) {
          case ATOM:
          case STRING:  gettxt_c(arg,Genbuf,&number_of_chars);
                        printf("\n%s\n",Genbuf);
                        return(SUCCESS);
          case INTEGER: getint_c(arg,&num);
                        printf("\n%d\n",num);
                        return(SUCCESS);
          default:      return(FAILURE);
     }
}

/* "promptfor" displays its second argument as a prompt
to the user.  It then accepts input from the user and
succeeds if the input is valid. */
int promptfor(typeneeded,prompt,returnval)
int typeneeded;
reftype prompt,returnval;
{
     int prompttype, length;
          long usrval;
     char *endptr;

     prompttype=findtype_c(prompt);
     if (findtype_c(returnval) != UNDEF ||
        (prompttype != ATOM && prompttype != STRING))
          return(FAILURE);
     gettxt_c(prompt,Genbuf,&length);
     printf("\n%s",Genbuf);
     fflush(stdin);
     if (typeneeded = = INTEGER) {
          scanf("%6s",Genbuf);
          usrval = strtol(Genbuf,&endptr,10);
          if (*endptr != NULL || labs(usrval) > INT_MAX)
               return(FAILURE);     /* fail on invalid input */
          putint_c((int)usrval,returnval);
          return(SUCCESS);
     }
     if (typeneeded = = ATOM) {
          scanf("%20s",Genbuf);
          putatm_c(strlwr(Genbuf),strlen(Genbuf),returnval);
          return(SUCCESS);
     }
     return(FAILURE);
}

/* Store copy of "text" in the dynamically sized global buffer */
int stash(text)
char *text;
{
      char *calloc_failed = NULL;

      if (Hold.bufinuse = = YES)
           return(FAILURE);
      Hold.buf = calloc(strlen(text)+1,sizeof(char));
      if (Hold.buf = = calloc_failed)
          return(FAILURE);
      strcpy(Hold.buf,text);
      Hold.bufinuse = YES;
              return(SUCCESS);
}

/* Free storage in the dynamically sized global buffer */
int release()
{
      if (Hold.bufinuse = = YES) {
           free(Hold.buf);
           Hold.bufinuse = NO;
      }
      return(SUCCESS);
}
```

Listing 2. *(Continued on following page)*

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```
/* Save a copy of "text" using stash() to allocate storage  */
int holdthis(text)
reftype text;
{
     int length, texttype;

     texttype = findtype_c(text);
     if (texttype != ATOM && texttype != STRING)
          return(FAILURE);
     gettxt_c(text,Genbuf,&length);
     return(stash(Genbuf));
}

/* "displayname" displays a full name to the screen. It is
    designed to illustrate use of dynamically sized global
    buffers to store data in between returns to PROLOG.
    Here, the PROLOG procedures "any_more_names_to_output"
    invoke the "holdthis" function to save the first name
    in a global buffer.  Then "displayname" is invoked
    with the middle and last names, so that all three are
    available for simultaneous output.  Note that this
    approach is used here for didactic reasons only since
    a more straightforward solution here would have been
    to define a new dispatch function, "c_dispatch_4,"
    that accepted four arguments while maintaining the
    PROLOG-to-C communication convention.*/
int displayname(middlename,lastname)
reftype middlename,lastname;
{
     int length;
     char *middle=Genbuf, last[80];

          if (Hold.bufinuse = = NO)   /* Fail if the first */
          return(FAILURE);          /* name is not in Hold.buf */
     gettxt_c(middlename,middle,&length);
     gettxt_c(lastname,last,&length);
     middle[0] = toupper(middle[0]);
     last[0] = toupper(last[0]);
     Hold.buf[0] = toupper(Hold.buf[0]);
     printf("\n     %-20s     %-20s     %-20s",Hold.buf,middle,last);
     release();
     return(SUCCESS);
}

/* Issue the top-level prompt and return the user response
   as a PROLOG atom. */
int query_user(command)
reftype command;
{
     if (findtype_c(command) != UNDEF)
          return(FAILURE);
     printf("\nCMD>");
     fflush(stdin);
     scanf("%6s",Genbuf);
     putatm_c(strlwr(Genbuf),strlen(Genbuf),command);
          /* putatm_c converts a C array of char */
          /* to a PROLOG atom. */
     return(SUCCESS);
}
```

Listing 2. *(Continued from preceding page)*

SAS Institute Inc. Announces

Lattice C Compilers for Your IBM Mainframe

Two years ago...

SAS Institute launched an effort to develop a subset of the SAS® Software System for the IBM Personal Computer. After careful study, we agreed that C was the programming language of choice. And that the Lattice® C compiler offered the quality, speed, and efficiency we needed.

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Development had progressed so well that we expanded our efforts to include the entire SAS System on a PC, written in C. And to insure that the language, syntax, and commands would be identical across all operating systems, we decided that all future versions of the SAS System—regardless of hardware—would be derived from the same source code written in C. That meant that we needed a C compiler for IBM 370 mainframes. And it had to be good, since all our software products would depend on it.

So we approached Lattice, Inc. and asked if we could implement a version of the Lattice C compiler for IBM mainframes. With Lattice, Inc.'s agreement, development began and progressed rapidly.

Today...

Our efforts are complete—we have a first-rate IBM 370 C compiler. And we are pleased to offer this development tool to you. Now you can write in a single language that is source code compatible with your IBM mainframe and your IBM PC. We have faithfully implemented not only the language, but also the supporting library and environment.

Features of the Lattice C compiler for the 370 include:

- **Generation of reentrant object code.** Reentrancy allows many users to share the same code. Reentrancy is not an easy feature to achieve on the 370, especially if you use non-constant external variables, but we did it.
- **Optimization of the generated code.** We know the 370 instruction set and the various 370 operating environments. We have over 100 staff years of assembler language systems experience on our development team.
- **Generated code executable in both 24-bit and 31-bit addressing modes.** You can run compiled programs above the 16 megabyte line in MVS/XA.
- **Generated code identical for OS and CMS operating systems.** You can move modules between MVS and CMS without even recompiling.
- **Complete libraries.** We have implemented all the library routines described by Kernighan and Ritchie (the informal C standard), and all the library routines supported by Lattice (except operating system dependent routines), plus extensions for dealing with 370 operating environments directly. Especially significant is our byte-addressable Unix®-style I/O access method.
- **Built-in functions.** Many of the traditional string handling functions are available as built-in functions, generating in-line machine code rather than function calls. Your call to move a string can result in just one MVC instruction rather than a function call and a loop.

In addition to mainframe software development, you can also use our new cross-compiler to develop PC software on your IBM mainframe. With our cross-compiler, you can compile Lattice C programs on your mainframe and generate object code ready to download to your PC.

With the cross-compiler, we also offer PLINK86™ and PLIB86™ by Phoenix Software Associates Ltd. The Phoenix link-editor and library management facility can bind several compiled programs on the mainframe and download immediately executable modules to your PC.

Tomorrow...

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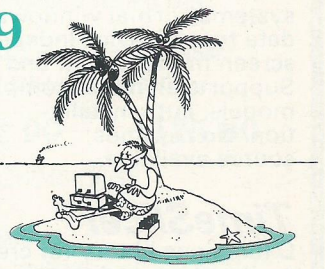

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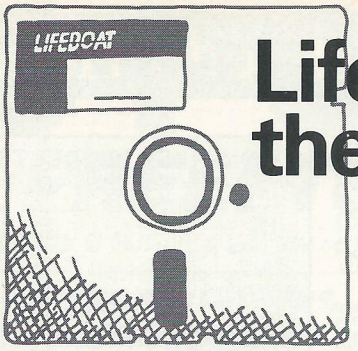

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Object-Oriented Programming with SCOOPS

Implementing the scissors-paper-stone game with this facility of LISP-based PC Scheme shows off the benefits of object-oriented programming

By John D. McGregor

In his column "Scissors, paper, stone: A tournament of Schemes,"[1] Brian Hayes developed an interesting implementation of this popular child's game using a dialect of LISP from Texas Instruments called PC Scheme.[2]

In addition to presenting the special features of Scheme, a central theme of Hayes's column was the power of returning procedures as the result of a function. This approach was taken to provide a degree of data abstraction as well as a method for saving the state of a set of variables.

After reviewing the implementation and the reasons for using a procedure to return a procedure, I was struck by the similarity of this technique with an object-oriented approach. Since I happened to be looking for a simple object-oriented example to use in a class, I immediately went to work on a sample system. PC Scheme includes an object-oriented facility, the Scheme Object-Oriented Programming System (SCOOPS), and thus was a natural choice for the implementation.

This article gives a brief introduction to object-oriented programming in general and the features of SCOOPS in particular. The basic features of this implementation follow those in the Hayes article to aid you in comparing the two approaches. Before discussing objects, let's review the game.

The simplicity of this game makes it a good example. The cyclic arrangement of values (Figure 1) means there is no sure offense, but it is possible to construct a variety of defenses and strategies.

In this game, two players each choose a move from the three possible. The winner is decided based on the relationships shown in Figure 1. One point is scored for every match a player wins. An implementation of this game should include representations for the two players, with appropriate procedures for generating moves.

In his discussion, Hayes was concerned with the privacy of the score. He didn't want players that could alter the score to be implemented. Thus he created a separate procedure to protect the score. In my implementation, an object (the Referee) provides this protection. Before describing in detail this object-oriented implementation, an introduction to objects is in order.

Objects

The designer using object-orientation seeks to identify the major entities in the developing system. Objects are developed to describe each of the entities. An **object** is a collection of data and procedures that operate on that data. The data of the object represents a private memory for the object. The procedures associated with the object are the only legitimate operators for that data.

Data base systems, expert systems, and other types of systems are benefiting from the object-oriented approach. One reason for the growing attention to this technique is its support of data encapsulation. The data in an object can only be acted upon by the procedures contained within the object. An outside entity informs the object what it wants done, such as displaying a data value, but it does not tell the object how to carry out the task. The exact details of the data structures are hidden from the outside entity.

A second reason for the growing importance of object-oriented programming is the ability it provides to save the local state. In a procedural language, local variables do not retain their values between invocations of the procedure. While global variables can be used to retain values, the data is no longer within the protective boundaries of a single procedure. Although the variables of an object behave like local procedural variables in some ways, they can retain their values between messages to the object.

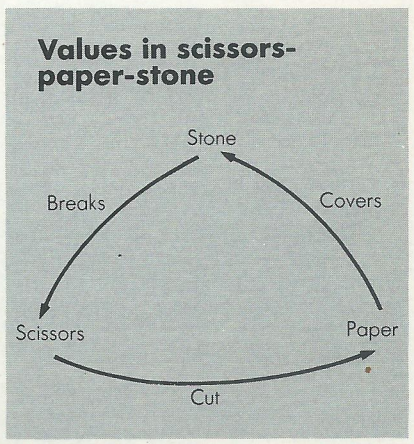

Figure 1.

Classes and instances. In PC Scheme, an object is implemented by first defining a class. A **class** can be thought of as a template for a category of objects. This basic definition reserves a slot for each of the data items that make up the local memory of the object. Consider a possible SCOOPS definition for the object class representing a computer science faculty member:

```
(define-class cs-faculty-member
      (classvars dept-chair)
      (instvars name ss-number specialty))
```

This statement creates a class with four variables, but it is only a definition. This abstraction must be instantiated before memory is allocated to store values. An instance of this class would be created by a statement like:

```
(define JOHN (make-instance
   cs-faculty-member
         'dept-chair    'BILL
         'name          "John McGregor"
         'ss-number     '000-00-0000
         'speciality    'AI          ))
```

The class variable *dept-chair* is global to the *cs-faculty-member* class. Thus each instance sees the same value for the *dept-chair* variable, has access to this value, and can modify it. Any modification of a class variable is immediately available to all instances of that class.

The values of the instance variables, name, Social Security number, and specialty are local to their particular instance. Their values can only be altered by the methods associated with that instance. Even though these variables are local, their values are retained between operations on the instance.

Methods and messages. The procedures associated with an object are termed methods. A **method** acts on the data associated with its object. A method to change a faculty member's specialty might look like:

```
(define-method (cs-faculty-member
   change-specialty)(new-value)
      (set! specialty new-value))
```

A method is activated by sending a message to the instance that is to be the receiver of the action. A message is made up of the keyword *SEND,* the identifier for a particular instance, a selector that is the name of one of the object's methods, and any arguments needed for the method. A message to activate the method in the previous example would be stated as:

```
(send JOHN change-specialty
   "Graphics")
```

An important and much-debated concept in object-oriented systems is early vs. late bindings. Delaying binding to the time of message passing allows a number of classes to possess the same message selectors, which are implemented internally to the objects in different ways, providing a higher degree of abstraction.

Language implementations such as SCOOPS and Objective-C provide for late bindings and thus for developing a set of abstract operations common across many classes. (See the accompanying sidebar, "Object-oriented implementations," for more on object-oriented languages.)

An object definition creates a template from which specific instances are defined. An object includes both local data storage and a set of associated methods for manipulating that data. Instance variables retain their values between messages to the object. If methods do not exist to manipulate certain of the object's variables, those values cannot be changed by outside agents.

```
;CLASS GAME
;THIS CLASS IS A SHELL THAT INSTANTIATES A REFEREE INSTANCE TO CONTROL
;THE GAME.  IT THEN SIGNALS THE REFEREE INSTANCE TO BEGIN THE GAME
;
(DEFINE-CLASS GAME
    (INSTVARS (WINNING-SCORE 15) THE-REFEREE INSTRUCTIONS)
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (GAME RESET-WINNING-SCORE)()
    (BEGIN (DISPLAY "ENTER VALUE FOR WINNING SCORE ")
           (SET! WINNING-SCORE (READ))))
(DEFINE-METHOD (GAME START)()
    (BEGIN
           (DISPLAY "DO YOU WANT TO SET GAME VALUES? (Y/N) ")
           (SET! INSTRUCTIONS (READ-CHAR))
           (COND ((OR (EQV? INSTRUCTIONS #\y) (EQV? INSTRUCTIONS #\Y))
                 (RESET-WINNING-SCORE)))
           (SET! THE-REFEREE (MAKE-INSTANCE REFEREE))
           (SEND THE-REFEREE START-GAME)))
;
;CLASS REFEREE
;THE CURRENT INSTANCE OF REFEREE SIGNALS EACH PLAYER TO MAKE A MOVE.
;IT DETERMINES THE WINNER OF EACH MATCH, KEEPS SCORE, AND
;TERMINATES A GAME WHEN THE WINNING SCORE IS REACHED
;
(DEFINE-CLASS REFEREE
    (INSTVARS (SCORE1 0) (SCORE2 0) MOVE-PLAYER-1 MOVE-PLAYER-2
    PLAYER-1 PLAYER-2 )
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (REFEREE START-GAME) ()
    (BEGIN
           (SET! PLAYER-1 (MAKE-INSTANCE PLAYER))
           (SET! PLAYER-2 (MAKE-INSTANCE PLAYER))
           (PLAY)
           (WRITELN "GAME COMPLETED")))
(DEFINE-METHOD (REFEREE PLAY) ()
    (BEGIN (DO ((I 1 (1+ I)))((OR (=? SCORE1 WINNING-SCORE)(=? SCORE2
                                                    WINNING-SCORE)))
```

Listing 1. *(Continued on following page)*

First implementation

A simple implementation of the scissors-paper-stone game is presented in Listing 1. The game is represented using three object classes: *Game, Referee,* and *Player.* The attributes (instance variables) for each class are shown in Figure 2.

The top-level *Run* function begins the game by generating an instance of class *Game* identified as *THIS-GAME.*

Game. The *Game* object is the overall manager of the simulation. The instance of the *Game* object, which is produced by *Run,* is responsible for generating an instance of the *Referee* object. *Game* also gives the user the opportunity to set the size of the winning score. *THIS-GAME* then signals the *Referee* instance to begin play by sending the message "START-GAME."

PC Scheme does not support class definitions as objects so it is not possible to generate instances by sending a message to the class definition, as one might

```
      (SET! MOVE-PLAYER-1 (SEND PLAYER-1 MAKE-MOVE))
      (SET! MOVE-PLAYER-2 (SEND PLAYER-2 MAKE-MOVE))
      (WRITELN "    " MOVE-PLAYER-1 #\TAB MOVE-PLAYER-2)
      (SEND PLAYER-1 TRACK-MOVE MOVE-PLAYER-2)
      (SEND PLAYER-2 TRACK-MOVE MOVE-PLAYER-1)
      (COND ((OR (AND (EQUAL? MOVE-PLAYER-2 'SCISSORS)
                      (EQUAL? MOVE-PLAYER-1 'PAPER))
                 (AND (EQUAL? MOVE-PLAYER-2 'PAPER)
                      (EQUAL? MOVE-PLAYER-1 'STONE))
                 (AND (EQUAL? MOVE-PLAYER-2 'STONE)
                      (EQUAL? MOVE-PLAYER-1 'SCISSORS)))
                 (SET! SCORE2 (1+ SCORE2)))
                 ((OR (AND (EQUAL? MOVE-PLAYER-1 'SCISSORS)
                           (EQUAL? MOVE-PLAYER-2 'PAPER))
                      (AND (EQUAL? MOVE-PLAYER-1 'PAPER)
                           (EQUAL? MOVE-PLAYER-2 'STONE))
                      (AND (EQUAL? MOVE-PLAYER-1 'STONE)
                           (EQUAL? MOVE-PLAYER-2 'SCISSORS)))
                      (SET! SCORE1 (1+ SCORE1)))
                 (ELSE
                      (WRITELN "DRAW ON THIS MATCH")))
            (COND ((=? SCORE1 WINNING-SCORE)
                      (NEWLINE )(DISPLAY "  PLAYER-1 WON"))
                  ((=? SCORE2 WINNING-SCORE)
                      (NEWLINE)(DISPLAY "  PLAYER-2 WON"))))))
;
;CLASS PLAYER
;TWO INSTANCES OF PLAYER ARE INSTANTIATED FOR EACH GAME
;
(DEFINE-CLASS PLAYER
    (INSTVARS  (OP-1 0)(OP-2 0) (OP-3 0) CURRENT-MOVE
               (MOVES (VECTOR 'STONE 'PAPER 'SCISSORS)))
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (PLAYER MAKE-MOVE)()
    (BEGIN (SET! CURRENT-MOVE  (VECTOR-REF MOVES (RANDOM 3)))
           (CAR (LIST CURRENT-MOVE))))
(DEFINE-METHOD (PLAYER TRACK-MOVE)(VAL)
    (BEGIN (COND ((EQUAL? VAL 'STONE) (SET! OP-1 (1+ OP-1)))
                 ((EQUAL? VAL 'PAPER) (SET! OP-2 (1+ OP-2)))
                 ((EQUAL? VAL 'SCISSORS) (SET! OP-3 (1+ OP-3))))))
(DEFINE RUN
    (LAMBDA () (DEFINE THIS-GAME (MAKE-INSTANCE GAME))
           (SEND THIS-GAME START)))
```

Listing 1. *(Continued from preceding page)*

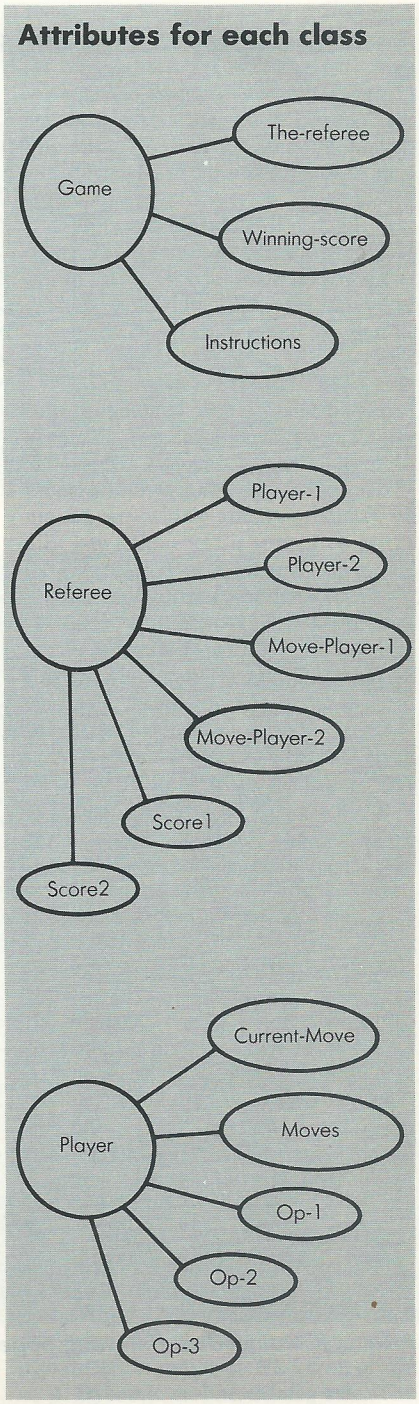

Figure 2.

Relationship of classes and instances for simulation

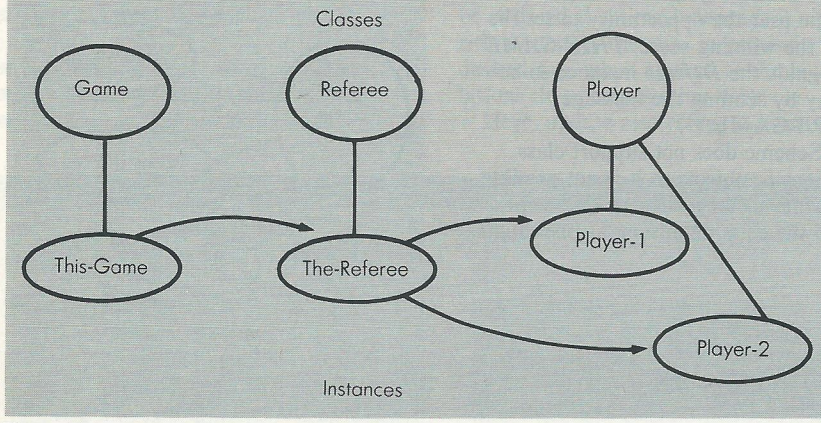

Figure 3.

```
; class Window
; Window class displays output to screen
; This class uses pop-up windows, and LISP handles overlap
; automatically
;
(define-class window
   (instvars x-origin y-origin x-size y-size title name)
   (options gettable-variables settable-variables inittable-variables))
(define-method (window create) ()
   (begin (set! name (make-window title #!true))
          (window-set-size! name y-size x-size)
          (window-set-position! name y-origin x-origin)))
(define-method (window move) (new-x new-y)
   (begin (window-popup-delete name)
          (window-set-position! name new-y new-x)
          (window-popup name)))
(define-method (window show) ()
   (window-popup name))
(define-method (window erase) ()
   (window-popup-delete name))
;
;CLASS GAME
;THIS CLASS IS A SHELL THAT INSTANTIATES A REFEREE INSTANCE TO CONTROL
;THE GAME.  IT THEN SIGNALS THE REFEREE INSTANCE TO BEGIN THE GAME
;
(DEFINE-CLASS GAME
    (INSTVARS (WINNING-SCORE 15) THE-REFEREE INSTRUCTIONS)
    (MIXINS WINDOW)
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (GAME RESET-WINNING-SCORE)()
    (BEGIN (NEWLINE NAME)
           (DISPLAY "ENTER VALUE FOR WINNING SCORE " NAME)
           (SET! WINNING-SCORE (READ NAME))))
```

Listing 2. *(Continued on following page)*

in Smalltalk. Figure 3 shows the relationship of the classes and instances for the overall simulation. The arrows illustrate the direction of messages.

Referee. The referee is the central controller of the game. The *Referee* object makes two instances of the *Player* class. After setting up a table for showing game moves, the *Referee* instance invokes its *PLAY* method to begin a game.

Note that in many object-oriented implementations, the variable *self* is included in each new class by inheritance from a root *Object* class. This variable is used by an object to send a message to itself to invoke another method. PC Scheme allows one method to directly invoke another method for the same object.

The referee signals each player when a new move is needed by sending them a "MAKE-MOVE" message. Once both players have responded with new moves, the referee determines the winner (if there is one) of each match by examining the contents of the *MOVE-PLAYER-1* and *MOVE-PLAYER-2* variables.

The referee also maintains the score for each player and declares a winner. Since no method allows an outside agent to change the score, it is protected. The referee also notifies each player of the move made by the other player.

Player. Each player is responsible for generating moves when they are requested by the referee. In this implementation, the players simply use a randomly generated value for one of the three moves. The players also record their opponent's moves but make no use of the information at present.

Inheritance

Object-oriented systems handle complexity by building a system in layers. New classes gain many of their capabilities by inheriting the capabilities of previously defined, usually more general, objects.

Windows. The previous implementation of SCOOPS did a very poor job of output. In Listing 2, the new object class *Window* is added. This class provides a set of variables and methods for creating and displaying windows. Each of the existing objects has been modified to inherit it from the window class by adding the statement *(mixins window)* to the definition for each of the classes. This state-

```
;CLASS REFEREE
;THE CURRENT INSTANCE OF REFEREE SIGNALS EACH PLAYER TO MAKE A MOVE.
;IT DETERMINES THE WINNER OF EACH MATCH, KEEPS SCORE, AND
;TERMINATES A GAME WHEN THE WINNING SCORE IS REACHED
;
(DEFINE-CLASS REFEREE
    (INSTVARS (SCORE1 0) (SCORE2 0) MOVE-PLAYER-1 MOVE-PLAYER-2
    PLAYER-1 PLAYER-2 X)
    (MIXINS WINDOW)
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (REFEREE START-GAME) ()
    (BEGIN
          (SET! X-ORIGIN 10) (SET! Y-ORIGIN 4)
          (SET! X-SIZE   45) (SET! Y-SIZE   8)
          (SET! TITLE "REFEREE")
          (CREATE) (SHOW)
          (SET! PLAYER-1 (MAKE-INSTANCE PLAYER
                              'X-ORIGIN 5
                              'TITLE    "PLAYER - 1"))
          (SET! PLAYER-2 (MAKE-INSTANCE PLAYER
                              'X-ORIGIN 40
                              'TITLE    "PLAYER - 2"))
          (PLAY)
          (WRITELN "GAME COMPLETED")))
(DEFINE-METHOD (REFEREE PLAY) ()
    (BEGIN (DO ((I 1 (1+ I)))((OR (=? SCORE1 WINNING-SCORE)
                                  (=? SCORE2 WINNING-SCORE)))
          (SET! MOVE-PLAYER-1 (SEND PLAYER-1 MAKE-MOVE))
          (SET! MOVE-PLAYER-2 (SEND PLAYER-2 MAKE-MOVE))
          (SEND PLAYER-1 SHOW-MOVE)
          (SEND PLAYER-2 SHOW-MOVE)
          (SEND PLAYER-1 TRACK-MOVE MOVE-PLAYER-2)
          (SEND PLAYER-2 TRACK-MOVE MOVE-PLAYER-1)
          (COND ((OR (AND (EQUAL? MOVE-PLAYER-2 'SCISSORS)
                          (EQUAL? MOVE-PLAYER-1 'PAPER))
                     (AND (EQUAL? MOVE-PLAYER-2 'PAPER)
                          (EQUAL? MOVE-PLAYER-1 'STONE))
                     (AND (EQUAL? MOVE-PLAYER-2 'STONE)
                          (EQUAL? MOVE-PLAYER-1 'SCISSORS)))
                 (SET! SCORE2 (1+ SCORE2))
                 (SHOW) (SHOW-SCORE))
                ((OR (AND (EQUAL? MOVE-PLAYER-1 'SCISSORS)
                          (EQUAL? MOVE-PLAYER-2 'PAPER))
                     (AND (EQUAL? MOVE-PLAYER-1 'PAPER)
                          (EQUAL? MOVE-PLAYER-2 'STONE))
                     (AND (EQUAL? MOVE-PLAYER-1 'STONE)
                          (EQUAL? MOVE-PLAYER-2 'SCISSORS)))
                 (SET! SCORE1 (1+ SCORE1))
                 (SHOW) (SHOW-SCORE))
                (ELSE
                   (SHOW) (SHOW-SCORE)
                   (DISPLAY "    DRAW ON THIS MATCH" NAME)))
          (COND ((=? SCORE1 WINNING-SCORE)
                 (DISPLAY "    PLAYER-1 WON" NAME))
                ((=? SCORE2 WINNING-SCORE)

(DEFINE-METHOD (GAME START)()
    (BEGIN
          (SET! X-ORIGIN 1) (SET! Y-ORIGIN 1)
          (SET! X-SIZE 68)  (SET! Y-SIZE   20)
          (SET! TITLE "STONE PAPER SCISSORS GAME")
          (CREATE)
          (SHOW)
          (DISPLAY "DO YOU WANT TO SET GAME VALUES? (Y/N) " NAME)
          (SET! INSTRUCTIONS (READ-CHAR NAME))
          (COND ((OR (EQV? INSTRUCTIONS #\y) (EQV? INSTRUCTIONS #\Y))
                 (RESET-WINNING-SCORE)))
          (ERASE)
          (SHOW)
          (SET! THE-REFEREE (MAKE-INSTANCE REFEREE))
          (SEND THE-REFEREE START-GAME)))

                   (DISPLAY "    PLAYER-2 WON" NAME)))
          (DO ((I 1 (1+ I)))          ;DELAY LOOP
              ((> I 7000) I)
              (SET! X 0))
          (ERASE)
          (SEND PLAYER-1 ERASE)
          (SEND PLAYER-2 ERASE))))
```

Listing 2. *(Continued on following page)*

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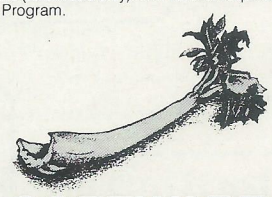

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```
(DEFINE-METHOD (REFEREE SHOW-SCORE)())
    (BEGIN (NEWLINE NAME)(NEWLINE NAME)
           (DISPLAY "          " NAME)
           (DISPLAY "Player 1" NAME)
           (DISPLAY "          " NAME)
           (DISPLAY "Player 2" NAME)
           (NEWLINE name)
           (DISPLAY "          " NAME)
           (DISPLAY SCORE1 NAME)
           (DISPLAY "                " NAME)
           (DISPLAY SCORE2 NAME)))
;
;CLASS PLAYER
;TWO INSTANCES OF PLAYER ARE INSTANTIATED FOR EACH GAME
;
(DEFINE-CLASS PLAYER
    (INSTVARS  (OP-1 0)(OP-2 0) (OP-3 0) CURRENT-MOVE
               (Y-ORIGIN 15) (X-SIZE 12) (Y-SIZE 4)
               (MOVES (VECTOR 'STONE 'PAPER 'SCISSORS)))
    (MIXINS WINDOW)
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (PLAYER MAKE-MOVE)()
    (BEGIN (SET! CURRENT-MOVE  (VECTOR-REF MOVES (RANDOM 3)))
           (CAR (LIST CURRENT-MOVE))))
(DEFINE-METHOD (PLAYER TRACK-MOVE)(VAL)
    (BEGIN (COND ((EQUAL? VAL 'STONE) (SET! OP-1 (1+ OP-1)))
                 ((EQUAL? VAL 'PAPER) (SET! OP-2 (1+ OP-2)))
                 ((EQUAL? VAL 'SCISSORS) (SET! OP-3 (1+ OP-3))))))
(define-method (player show-move) ()
    (begin (CREATE) (show)
           (newline name)
           (newline name)
           (DISPLAY "  " NAME)
           (display CURRENT-MOVE name)))
(DEFINE RUN
    (LAMBDA () (DEFINE THIS-GAME (MAKE-INSTANCE GAME))
           (SEND THIS-GAME START)))
```

Listing 2. ***(Continued from preceding page)***

Diagramming technique

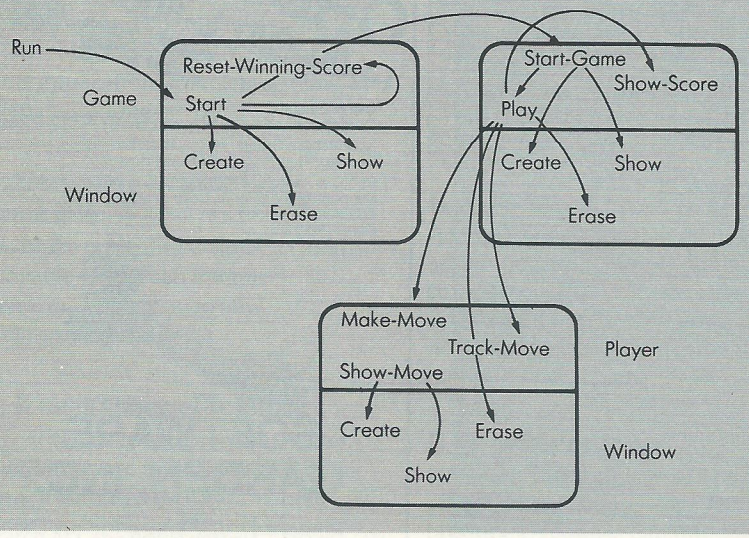

Figure 4.

ment defines, for example, a method *create* for the *Game, Referee,* and *Player* objects that allows instances of these objects to create windows for output purposes.

Inheritance means that the methods and variables defined in the superclass become part of the inheriting class. The instance variables defined in the window class become instance variables for each instance of the classes. Thus the inheriting class gains both capabilities and information without the class definition becoming more complex.

Figure 4 uses a diagramming technique proposed by W. Cunningham and K. Beck[3] to illustrate the layering of classes and interaction through messages. Note that superclasses are beneath the inheriting class, thus emphasizing that the appropriate method is found by a depth-first search.

Strategic decisions. As an additional example of inheritance, Listing 3 contains two additional class definitions: *ODDS-PLAYER* and *AVERAGE-PLAYER*. These two classes provide definitions of players that use a more sophisticated (though not by much) strategy for generating moves. *ODDS-PLAYER* selects as its next move the move most often used by its opponent, while *AVERAGE-PLAYER* selects the move least often used by its opponent.

These new classes illustrate the power of inheritance. Most of the variables and methods needed are obtained from the superclass *Player*. The *MAKE-MOVE* method defined in the new definitions has the same name and purpose as one of the original methods in *Player*. When a message invokes a method, a depth-first search begins at the class that defines the instance object and searches through the inheritance chain to find the appropriate code.

When an *ODDS-PLAYER* instance receives the message "ERASE," a search begins at the *ODDS-PLAYER* definition and continues down the chain until the appropriate code is found in the *WINDOW* definition. If the message were "MAKE-MOVE," the search would stop with *ODDS-PLAYER*, which has a *MAKE-MOVE* method defined and would not find the *MAKE-MOVE* meth-

od defined in *PLAYER*. Thus several method definitions may share the same name, but only the most recent definition will be used.

Comparing implementations

The concept of object-oriented programming is too recent to be highly standardized. G. Pascoe[4] gives four fundamental characteristics of object orientation: information hiding, data abstraction, dynamic binding, and inheritance.

SCOOPS supports information hiding by invoking methods through messages. The implementation of the method is hidden from the message sender. Data abstraction is achieved by the overloading of method selectors. Since SCOOPS is a LISP-based implementation, the usual dynamic binding process is utilized. Finally, as already discussed, SCOOPS supports inheritance of methods and variables using the *mixins* clause of the class definition statement.

Additional features are present in other languages that claim to be object-oriented. PC Scheme's SCOOPS facility is a useful object-oriented facility, but it is not complete when compared to some of the other available implementations.

What's missing. The differences begin with creating a new instance of an object. Objective-C and Smalltalk allow sending messages to a class definition. For example, if a Smalltalk image includes a definition for a *Frame* object, a new instance of *Frame* is created by the message "Frame new." Although this approach differs little from SCOOPS' *MAKE-INSTANCE*, a message approach would be more consistent.

To present a consistent interface, many object-oriented languages such as Smalltalk include the special instance variable *self* (as already mentioned), which is used by an object to send messages to itself. This ability allows all procedure activations to occur through messages.

SCOOPS does not have this variable, but object methods can be invoked as ordinary procedures by other methods within the object. In the *START-GAME* method of the *Referee* object, it would be more consistent to use *(Send self Play)* as opposed to *(Play)*.

The pluses. PC Scheme and several other implementations support a form of polymorphism. Scheme implements ad hoc polymorphism through function name overloading, which allows different objects to present the same interface to the outside world by having them all respond to the same messages. In Listing 3, for example, *ODDS-PLAYER* and *AVERAGE-PLAYER* instances each respond to "MAKE-MOVE" messages but use somewhat different algorithms.

Multiple inheritance is available in most LISP-based, object-oriented systems but not in C++ or most commercial versions of Smalltalk (with the

```
;CLASS PLAYER
;TWO INSTANCES OF PLAYER ARE INSTANIATED FOR EACH GAME
;
(DEFINE-CLASS PLAYER
    (INSTVARS  (OP-1 Ø)(OP-2 Ø) (OP-3 Ø) CURRENT-MOVE
               (Y-ORIGIN 15) (X-SIZE 12) (Y-SIZE 4)
               (MOVES (VECTOR 'STONE 'PAPER 'SCISSORS)))
    (MIXINS WINDOW)
    (OPTIONS GETTABLE-VARIABLES SETTABLE-VARIABLES INITTABLE-VARIABLES))
(DEFINE-METHOD (PLAYER MAKE-MOVE)()
    (BEGIN (SET! CURRENT-MOVE  (VECTOR-REF MOVES (RANDOM 3)))
           (CAR (LIST CURRENT-MOVE))))
(DEFINE-METHOD (PLAYER TRACK-MOVE)(VAL)
    (BEGIN (COND ((EQUAL? VAL 'STONE) (SET! OP-1 (1+ OP-1)))
                 ((EQUAL? VAL 'PAPER) (SET! OP-2 (1+ OP-2)))
                 ((EQUAL? VAL 'SCISSORS) (SET! OP-3 (1+ OP-3))))))
(define-method (player show-move) ()
    (begin (CREATE) (show)
           (newline name)
           (newline name)
           (DISPLAY "   " NAME)
           (display CURRENT-MOVE name)))
;
;  CLASS DEFINITION FOR ODDS-PLAYER
;  THIS DEFINITION INHERITS FROM PLAYER
;  THE ONLY DIFFERENCE IS THE MAKE-MOVE METHOD
;
(DEFINE-CLASS ODDS-PLAYER
(instvars x y)
  (MIXINS PLAYER)
  (OPTIONS GETTABLE-VARIABLES INITTABLE-VARIABLES SETTABLE-VARIABLES))
(DEFINE-METHOD (ODDS-PLAYER MAKE-MOVE)()
    (BEGIN (set! x (max op-1 op-2 op-3))
      (cond ((=? x op-1) (set! current-move 'stone))
            ((=? x op-2) (set! current-move 'paper))
            ((=? x op-3) (set! current-move 'scissors)))
      (CAR (LIST CURRENT-MOVE))))
;
;  CLASS DEFINITION FOR AVERAGE-PLAYER
;  THIS DEFINITION INHERITS FROM PLAYER
;  THE ONLY DIFFERENCE IS THE MAKE-MOVE METHOD
;
(DEFINE-CLASS AVERAGE-PLAYER
  (INSTVARS X)
  (MIXINS PLAYER)
  (OPTIONS GETTABLE-VARIABLES INITTABLE-VARIABLES SETTABLE-VARIABLES))
(DEFINE-METHOD (AVERAGE-PLAYER MAKE-MOVE)()
    (BEGIN (set! x (MIN op-1 op-2 op-3))
      (cond ((=? x op-1) (set! current-move 'stone))
            ((=? x op-2) (set! current-move 'paper))
            ((=? x op-3) (set! current-move 'scissors)))
      (CAR (LIST CURRENT-MOVE))))
```

Listing 3.

Difference between inheritances

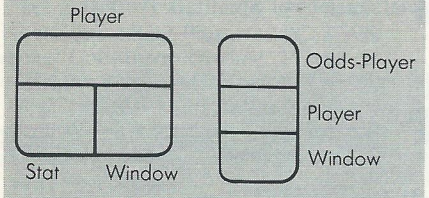

Figure 5.

exception of the Tektronix version). Inheritance allows an object to gain capabilities such as the use of windows or a way of presenting information.

Multiple inheritance allows an object to have more than one immediate predecessor. The statement *(mixins window quant)* would give the class containing this statement two approaches for presenting its data: visual and quantitative. Figure 5 shows the difference between the multilayered but still single inheritance of *ODDS-PLAYER, PLAYER, WINDOW,* and multiple inheritance.

The class definition statement of PC Scheme provides control over which variables can be manipulated. The *OPTIONS* clause of the *DEFINE-CLASS* statement gives the programmer the ability to determine which variables can be initialized, set, and retrieved. In each class definition in the listings, the *OPTIONS* clause does not include any variable names. This omission makes all variables in the object open for initialization and access through the *SET* and *GET* functions.

Changing the way we think

The implementations of the scissors-paper-stone game given in this article provide a focal point for investigating object-oriented programming. Brad Cox[5] views this style of programming as code-packaging. I believe the effect of this packaging technique extends to the basic design process and the way designers think.

Object-oriented design will soon have an impact on the development of a wide variety of systems. Elements of the class-instance way of thinking can be seen even in Ada's generics. This design technique is a natural extension of the moves to increase modularity, maintainability, and reusability of code. As systems become more complex and we seek to establish software factories, the characteristics of object-oriented design will be a basis for additional development.

Object-oriented implementations

Simula-67 introduced the earliest notions of classes and objects, but access to the content of objects was not restricted.

Smalltalk was developed by Alan Kay and Adele Goldberg at the Xerox Palo Alto Research Center, Palo Alto, Calif. The Smalltalk language operates in an interactive environment with editors, class browsers, and method compilers giving access to all parts of the system. Smalltalk is one of the most (if not the most) consistently object-oriented implementations. Even the most primitive data types, such as integers, are defined as objects.

CommonLoops is representative of several LISP-based implementations that blend object-oriented and procedure-oriented programming styles. The list-processing approach of LISP gives support for multiple-inheritance, which is not available in many of the other object-oriented languages, such as C++.

Objective-C is one of the object-oriented implementations designed as a front-end or preprocessor to a C compiler. With messaging being rated as 2 to 70 times slower than procedure calls, these products have the advantage of producing tight, fast code. Versions of these systems are tied to specific C compilers.

Knowledge Engineering Environment (KEE) is one of several knowledge programming environments that have grown out of the object-oriented arena. These represent particular applications to areas such as expert systems development. Generic capabilities for showing inheritance trees and the like are included in the system and inherited by the user's specialized objects to provide programmer support.

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John McGregor is an associate professor of computer science at Murray State University, Murray, Ky. He became interested in object-oriented programming while in a summer faculty research position at Lawrence Livermore National Laboratory, Livermore, Calif.

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Will the Real AI Language Please Stand Up?

By Harvey Newquist III

Artificial intelligence is perhaps the most overused—and abused—buzzword in the current age of computer science. The AI arena has been divided into several factions, all of which help distort its real benefits and potentials.

On the one hand we have the popular business media, which has billed AI as everything from the greatest creation since sliced bread to a worthless endeavor perpetuated by computer hucksters.

Then we have the vendors and users, caught in a continual tug-of-war over how to properly implement AI, how to integrate it with existing applications, which machines to run it on, where it fits best in a company's computing strategy, etc.

Finally, we have the hard-core researchers—those people who gave us AI in the first place. They spend their time thinking about thinking and coming up with new ways to create machines that more closely resemble humans and human capabilities.

Though these groups are quite separate, one simple question has begun to bind them together: Which language is best for developing AI applications, particularly expert systems and natural language interfaces?

Not since the whole concept of AI was developed has there been such chaos and confusion in the marketplace over the suitability of a programming language to the needs of the developer and user. So let's look briefly at the history of languages in AI and then see what's being done with them in 1987.

How it all began

The notion of artificial intelligence was conceived in 1956, when a group of gentlemen assembled for the Dartmouth Summer Conference to discuss ways to improve the capabilities of computers.

This small group was led by Massachusetts Institute of Technology researcher John McCarthy, who presented the term "artificial intelligence" to the group as a concept that they should all work to achieve.

Not coincidentally, McCarthy was also the inventor of a brand new language called LISP (LISt Processing). McCarthy's new programming language was symbolically oriented: it shunned the standard computer language process of employing numerical processing. It was with this language that the group hoped to develop computers and computer programs that would become truly intelligent.

After this first conference, the attendees returned to their respective universities—primarily MIT, Cambridge, Mass., and Carnegie-Mellon University, Pittsburgh, Pa. Small AI labs at these two schools were fostered to work on problems in artificial intelligence, particularly expert systems and robotics.

Within a few years, however, McCarthy's LISP began to mutate. As different organizations began to use LISP, they also began to customize the language to suit their own needs.

For instance, Bolt Beranek & Newman, the research and contract company, began developing its own version of LISP, known as BBN LISP, for internal use. But some of the people working on the project left to go to the Xerox Palo Alto Research Center (PARC) in Palo Alto, Calif., and they took this LISP with them. There it evolved again and became known as InterLISP-D.

At about the same time, researchers were leaving CMU and going to Stanford University, Stanford, Calif., where McCarthy had gone after leaving MIT. More LISPs made their way around the country, and no less than two dozen versions of the language appeared, some incompatible with others.

Since this was the researchers' language of choice, it was the first one used extensively for developing AI applications. Expert systems such as the medical programs CADUCEUS and MYCIN were written in LISP, as was the pioneering molecular analysis program known as DENDRAL.

Some of these languages were developed specifically in InterLISP. Extensive use of this language was the result of a time-sharing program set up by the National Science Foundation and Stanford, where the main computer ran—you guessed it—InterLISP.

So the initial AI developers were actually a fairly tight-knit group of less than 50 researchers who all decided to use the same basic language for their work. Most of these individuals knew each other as well, so they developed somewhat of a monopoly on what was going on in AI and what languages were to be used. Thus LISP became the standard language for the AI community, with little or no competition from other forms of programming languages.

On the foreign front

Now we turn our sights to Europe. Both France and Sweden had emerging AI projects going on in the early 1970s in a number of universities, most notably Sweden's Uppsala University and France's University of Marseilles.

The primary work coming out of Europe involved logic programming, another approach to emulating human thought processes. The French research project developed a language known as PROLOG (PROgramming in LOGic). It was more structured than LISP but was better for following lines of logic.

PROLOG finally made its way across the Atlantic in the early 1980s, where it met with huge resistance from the established AI community in the U.S. Much of the time between 1981 and 1986 was spent arguing the pros and cons of one language or the other.

By 1986, LISP almost triumphed. Its proponents had kept PROLOG at bay by convincing U.S. customers that it was more of a methodology than a full-featured language. The number of companies selling PROLOG in the U.S. at that time was less than a dozen.

But PROLOG had gone to Japan. There the Japanese Fifth Generation Project—designed to create knowledge-based hardware and software—decided to use PROLOG as the basis for all of its operations. This decision was based in large part on the fact that PROLOG was not a U.S. product and the Fifth Generation was aimed directly at assaulting the U.S. claim to the highest of high technology.

AI vs. conventional languages

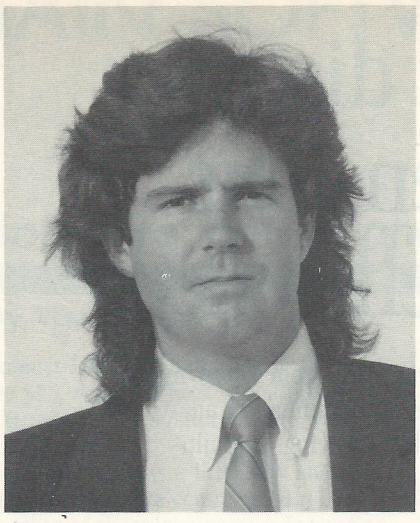
This brings us to the present state of affairs, but we have not yet looked at other languages. Just because the original AI researchers chose LISP doesn't mean that BASIC, FORTRAN, or COBOL won't work.

The difficulty with employing these languages in AI programming is that they don't have all the logic or symbolic facilities that make LISP or PROLOG a little more efficient at the development stage. But a good programmer can work around these shortcomings and create full-featured expert systems in any language.

For instance, one of the first expert system shells for the PC was developed by the U.K.'s Donald Michie in FORTRAN. Upon its introduction, this package—known as Expert-Ease—was the most successful PC tool available.

But languages of all sizes and shapes can be used for AI, and not just at the PC level. A division of Cullinet, Distributed Management Systems, has a COBOL expert system for IBM environments known as IMPACT. And IBM itself has an internal expert system for teaching music theory that was written in Pascal. With a little imagination, any language can be appropriate, given the programmer's familiarity with all its features and idiosyncracies.

Another way expert systems and various AI applications can be developed is through the use of object-oriented languages such as Smalltalk, Flavors, and OPS. Each of these has been employed for the creation of some very comprehensive applications, such as XCON, the infamous configuration expert used at



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XCON was developed in 1980 by DEC and CMU and was written in OPS5, an object language developed at CMU. XCON is believed to be the largest expert system running in day-to-day use anywhere in the world.

Many organizations see object orientation as a way to add intelligent capabilities to existing languages and create an enhanced programming environment. Object-oriented languages do not require the complete relearning of a whole separate language from the one that the programmer is already fluent in. In just the last two years, object orientation has grown from an AI curiosity into a very important part of programming at large.

Winds of change

So here we are in 1987. A major shift in control of the AI community has taken place, from a small group of researchers to the users.

Along with this shift has come a marked change in what types of languages are being used. There really aren't that many fully trained LISP hackers out there, simply because there hasn't been the time to train them. Plus, the specialized machines used to run LISP are expensive and require good, experienced programmers.

Users began looking for alternatives to LISP in early 1986 and saw that with a little work they could use C for their applications—or even run LISP on standard, general-purpose machines. This gave users a choice that enabled them to save money and use their resources more economically.

As a result, the LISP vs. PROLOG argument has become moot; now it's C vs. LISP. PROLOG appears to be taking a back seat to this new debate, but not for lack of trying. Case in point: Borland International's Turbo PROLOG has allegedly sold close to 100,000 copies since its introduction last year, allowing a whole new generation of programmers to become acquainted with the language.

But the pervasiveness of C and its relationship to UNIX, coupled with the voices of LISP vendors and researchers, has made these two languages the center of AI attention.

Some expert system companies have dropped LISP altogether, focusing on more flexible languages. Teknowledge, for instance, switched its LISP-based S.1 tool to C in late 1985 and now only supports its C versions. Inference Corp. and The Carnegie Group are still keeping the LISP versions of their expert system tools but plan on having C implementations available by the end of this year. Plus, the recent demise of LISP Machine Inc. and the troubles at LISP leader Symbolics have not made things any easier for those organizations trying to decide on which path to follow in developing AI applications.

On the other hand, a number of companies such as Lucid, Sun Microsystems, Apollo, and Franz Inc. have all attempted to make it easier for the mass market to use generally available machines and tools for AI development instead of relying on specialized machines and tools. These companies are focusing on general-purpose environments such as UNIX to help the spread of AI development.

So now we have C vs. LISP. Which is better? Depends on what you need. LISP is a tough language to port to a lot of machines; that happens to be one of C's strengths. C isn't so great at some of the screen interfaces found in a majority of expert systems; LISP has enough interface capabilities to keep even the most jaded programmer happy. And the list goes on.

The fact remains, however, that AI is not any particular language nor any particular programming style. No AI language is required for developing applications, just as no specific brand of gasoline is required to get your car running.

Developing an expert system or natural language application all boils down to a few very simple things. First, how comfortable is the programmer with a specific language? Second, what kind of machine is the application going to run on? Third, how much is the use of a certain language going to cost? (Management may argue that this should be the first consideration.)

And last, but certainly not least: Does it work?

Harvey Newquist III's column In Practice appears each month in AI EXPERT. *In addition, he is editor of the* AI TRENDS *newsletter and a contributing editor to* COMPUTERWORLD.

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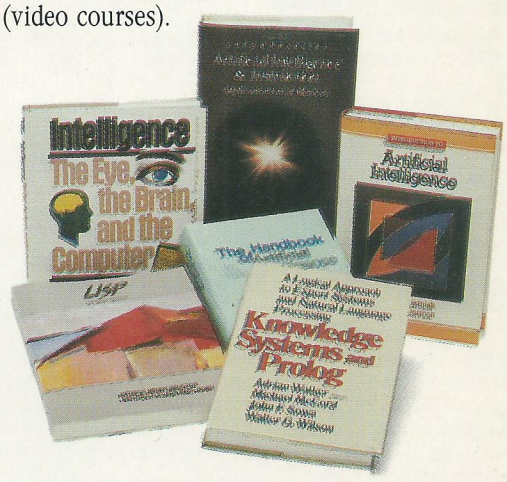

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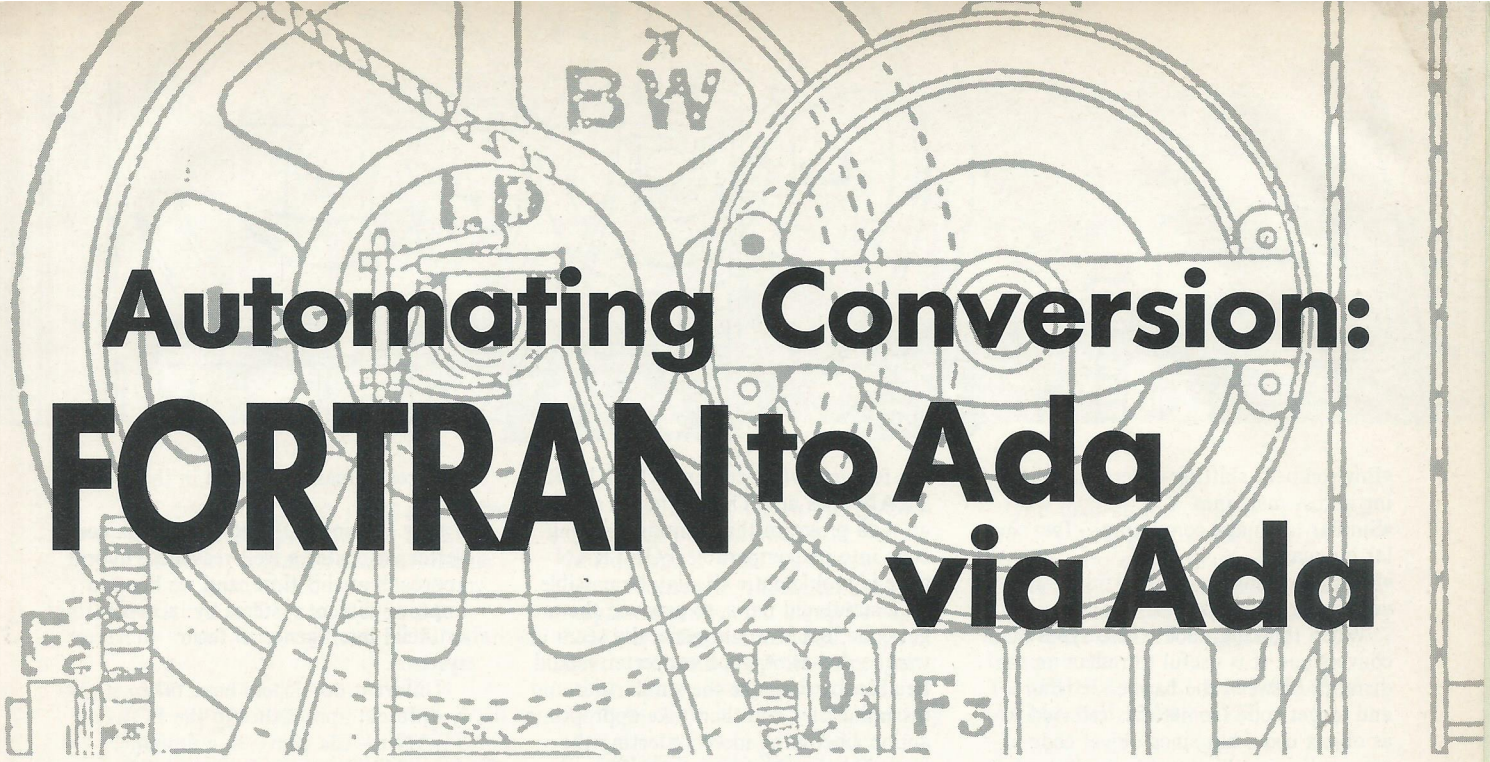


Automating Conversion: FORTRAN to Ada via Ada

By Lance B. Eliot and Floyd L. Holliday

The development and maintenance of software is hampered by a lack of robust tools for the software professional. One research effort to create such tools is the Knowledge-Based Systems Factory (KBSF) project; this article describes one tool that fits into the systems factory concept. The tool described is used to convert FORTRAN programs into Ada programs and is itself written in Ada.

Though the KBSF approach to the conversion process is not unique, many facets of the converter provide interesting insights into the similarities and differences of FORTRAN and Ada. As Ada becomes more widely adopted there is bound to be increased attention from traditional FORTRAN programmers as to how to develop Ada programs.

We hope to illuminate some of the dangers in creating blind Ada code based on FORTRAN reasoning, in the same way that the KBSF converter produces comparable Ada code for a given segment of FORTRAN code (functional but not elegant). Finally, we provide some speculation on the need to incorporate intelligence into a language-to-language converter such as FORTRAN-to-Ada, especially if full conversion is desired (such as producing true targeted code that is both understandable and maintainable).

The right tools

Much of the literature on software engineering decries the current set of tools available to software professionals.[1,2] Software can be a simple artifact or it can be a massive, tangled web of delicately balanced lines of code waiting for just the worst moment to become unreliable, frustrating the end user and developer alike.

What software professionals want is the same thing many other professions already have: tools to help them get their job done. But these tools are not of the manual variety; instead, the software professional desires automation to help produce automation.

Recent attempts to develop computer-aided software engineering (CASE) have met with moderate success.[3-5] The KBSF research project has explored the use of a production factory metaphor in an effort to develop CASE.[5] The Japanese have also adopted the factory notion for software development, but their use of the factory metaphor has been criticized as stifling creativity.[6]

In the KBSF a software professional is portrayed as a skilled craftsperson while the software factory deals with knowledge-based tools that "can focus on sophisticated machinery, manufacturing processes, and strategies for effectively organizing their use by large development teams."[6]

Automation in the KBSF assists, rather than replaces, skilled software engineers. Furthermore, the tools are of the heavy machinery type and are intended for large-scale software development.

Some of the tools in the current factory toolkit include:

- Language-directed editor generator
- Flow analyzer and testing system
- Configuration management system
- Window-based user interface and command processor
- Gist specification analyzer and simulator
- Document integration facility
- Spreadsheet application generator
- Project planning and scheduling system
- Knowledge-based project management support system

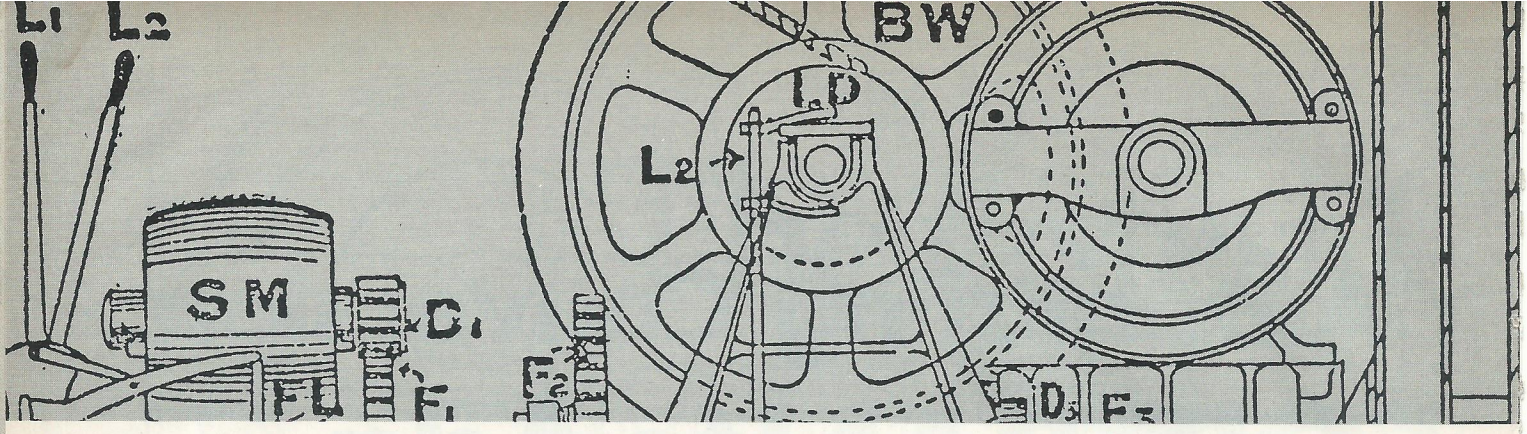
The KBSF is an incremental development effort, spanning several years of evolution. Since the project is part of a university research effort, the KBSF has been largely developed by graduate students under the direction of faculty.

Conversion and distance

One piece of work related to the KBSF, conversion, is the subject of this article. This word and process often strike fear in the hearts of many a software developer. Language-to-language converters have been around for years, and this section details some of their history. Following this discussion is a description of our FORTRAN-to-Ada converter. Finally, we consider the future directions for language-to-language converters.

The process of conversion can differ significantly depending upon the distance between the base and target languages. A range of distances is conveyed by considering some of the types of conversions possible:

- Formatting—Minor textual conversion
- Version changing—Converting within a language



•Environment shifting—Version changing across machines
•Similar language converting—Two similar languages
•Dissimilar language converting—Two very different languages

When thinking about these types of conversions, it is useful to reflect on the distance between the base code (source) and target code (sometimes referred to as object code, but since object code often implies machine code, we choose not to use the term here). Typically, a tool that formats a program doesn't require any great sophistication, and the base and target sets of code are different in only minor, textual fashion (indentation, blank lines, longer variable names, pagination, added notations, etc.).

The intermediate distances, such as version changing and environment shifting, are conversions between a base in language X and a target, also in language X. Thus we might have to convert FORTRAN II code to FORTRAN IV code or VAX FORTRAN to IBM FORTRAN. In some cases the distance between these same-language entities is quite small (approaching a formatting problem), while in other cases the distance is quite large.

Finally, conversion between two different languages can vary depending upon how similar or dissimilar the two languages appear to be. Some languages, such as a typical BASIC or FORTRAN, are fairly similar. In the latter case, much of the conversion process can rely on simple syntax changes. Yet even with a typical BASIC or FORTRAN the conversion can quickly become complicated if programmer tricks are allowed in the language.

For example, a BASIC program might be written in such a fashion as to take advantage of certain machine dependencies (16-bit words, I/O address locations, etc.). Trying to convert a tricky program into its comparable target code can be difficult—both for a human and a machine.

Other conversion issues

Some conversions are not practical at all. For example, Ada has an inherent tasking feature, while current ANSI FORTRAN does not. Thus trying to convert an Ada program that contains tasking code into its comparable FORTRAN code is problematic (it may be possible, on a simulated basis, to produce the target code, but it would generally seem unwise to do so). A good converter should be able to recognize the similarities and dissimilarities and then take appropriate action (including merely alerting the user that the change may not be practical).

Some conversions produce comparable code but do not exploit the capabilities of the target language. Again, consider a straight, sequential FORTRAN program that is being converted into Ada. Normally the resulting code would not exploit the tasking feature of Ada. Thus, providing strict conversion may not be desired. Instead, the converter might be required to redo the base so that it is improved in the target language.

Unfortunately, an awkward trade-off begins to emerge as the absolute difference between the produced base and target begin to stretch sensible limits. If a programmer tries to compare the base and target, the two may seem to be entirely different programs! At the point where the base and target vary to such a large degree, a person using the conversion may find that previous internally focused documentation has become obsolete—making maintenance a tougher job than it may have been to begin with.

Many of these topics generate a host of concerns. Conversion is an interesting problem related to compiler theory and other computer science topics. For a discussion of additional issues in the conversion debate, see references 2 and 7. A list of several commercial conversion products is also given in reference 7.

Converting FORTRAN to Ada

Ada is the new kid on the block, FORTRAN the old. Organizations wishing to adopt Ada often will already have an entrenched investment in existing FORTRAN code.

One approach to what to do with all that FORTRAN code is to convert it into Ada code, either by hand or machine. Currently, even the best FORTRAN-to-Ada automatic converter still requires human assistance in the tougher cases.

Our current FORTRAN-to-Ada converter advocates a well-reasoned, hybrid approach at this time, and we hope to improve current systems by incorporating artificial intelligence in future converter systems.

Different developers have taken slightly different approaches in the FORTRAN-to-Ada conversion design.[8-11] Arguably, the most significant difference revolves around the issue of how close the target should logically be to its original base. J. Slape and P. Wallis[10-11] tend to favor not maintaining the new Ada, as though it was still in its base FORTRAN version (in other words, the converter can produce target code that is dramatically different from its given base).

Our philosophy is to tread a thin line between producing the closest equivalent code and the its-not-the-same semantically farther away code. We want to produce generated Ada code that is understandable and maintainable in the sense of the original FORTRAN code.

Our wish list continues. We do not want to undermine the portability and efficiency of the FORTRAN code. We do not want to produce Ada code that is much bigger than the base FORTRAN. The design of the FORTRAN program should be reusable with the new Ada code. These goals, and others, present a formidable barrier.

The KBSF approach

Choosing which language to write the converter in is often a problem itself. The KBSF converter is written in Ada. We wanted a tool that would incorporate many of the preferred aspects of good software, and Ada met our criteria (portability, understandability, and maintainability). As a result, the converter also serves an obviously useful purpose if it is selected by adopters of Ada.

The Ada we used is the ANSI standard described in reference 12; when we refer to FORTRAN we mean the ANSI

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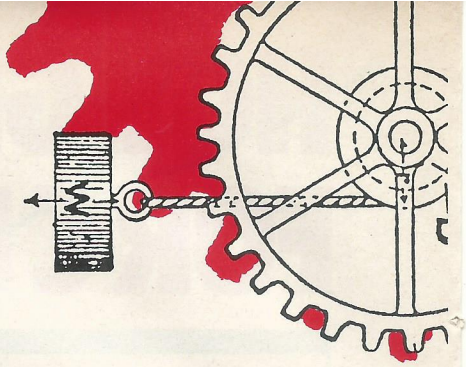


```
Sample FORTRAN base containing functions

        program testl
        integer funtst
        integer array(3,5)
        array(1,2) = array(3,4)
        i= funtst(3,1)
        stop
        end
        integer function funtst(a,b)
        integer a,b
        if (a .gt. b .and. a+l .gt. b .or. a-l .le. b) then
          funtst = a + (b-b)
        elseif (a .gt. b .and. a+l .gt. b .and. a+2 .gt. b) then
          funtst = a + -b
        endif
        if (a .gt. b .and. a+l .gt. b .or. a-l .le. b) goto 3
          funtst = a+(b*b)
          goto 4
3       continue
          funtst = (a+b) * b
4       return
        end
```

Listing 1A.

```
Sample Ada conversion generated from 1A

-- The main program is:
with FORTRAN; use FORTRAN;
        procedure TEST1;

-- The procedure and functions are:
with FORTRAN; use FORTRAN;
        function FUNTST(A : in INTEGER;
                        B : in INTEGER) return INTEGER;

with TEXT_IO;
with FUNTST;
procedure TEST1 is -- main program
  N_ARRAY : array(1..3,1..5) of INTEGER;
  I : INTEGER;
begin
  N_ARRAY(1,2) := N_ARRAY(3,4);
  I := FUNTST(3,1);
  raise FORTRAN_STOP;
exception
when FORTRAN_STOP =>
  TEXT_IO.PUT_LINE("FORTRAN STOP");
end TEST1;
with TEXT_IO;

function FUNTST(A : in INTEGER;
                B : in INTEGER) return INTEGER is
  FUNTST_RESULT : INTEGER;
begin
  if (A>B and A+1>B) or A-1<=B then
    FUNTST_RESULT := A+(B-B);
  elsif A>B and A+1>B and A+2>B then
    FUNTST_RESULT := A+(-B);
  end if;
  if (A<=B or A+1<=B) and A-1>B then
    FUNTST_RESULT := A+(B*B);
  else
    null;
    FUNTST_RESULT := (A+B)*B;
  end if;
  return FUNTST_RESULT;
end FUNTST;
```

Listing 1B.

X3.9 1978 standard.[13] Other converters sometimes pick specific vendor versions of Ada or FORTRAN, but we chose the standards.

FORTRAN tends to describe its modular structures in one set of terms, Ada in another. Thus we use the word "subprograms" to refer to Ada subprograms and FORTRAN procedures, "procedures" to refer to Ada procedures and FORTRAN subroutines, and "function" to refer to the same module types in both languages.

FORTRAN has essentially two fundamental data types: scalar and array. The FORTRAN scalar class is considered an atomic element in our view. Ada has both predefined types and program-defined types. The FORTRAN type *COMPLEX* (an example of an atomic element in FORTRAN) is viewed as a compound, program-defined record type in our targeted Ada code.

How the converter works

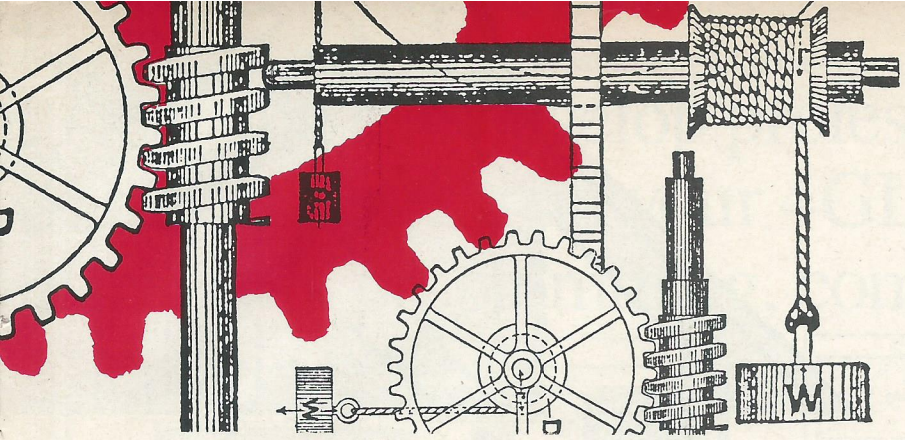
The KBSF converter makes two passes through the FORTRAN base. Unlike some other converters, no prior modification of the FORTRAN code is necessary—we assume the FORTRAN code is in its pure form (possibly a mess).

A FORTRAN compiler might be expected to compile subprograms independently, but in our case this is not a sensible approach. The entire FORTRAN code, including the main program and all of its associated subprograms, is used during the conversion process.

The FORTRAN code is actually read twice, once during each pass. In the first pass the code is scanned and an intermediate form produced. As part of the intermediate form, a special deep structure that reflects various aspects of the FORTRAN base is created. The deep structure is then analyzed for global consequences.

During the second pass the deep structure is enhanced (details added in) and the Ada target produced. This is accomplished by walking in a preordered manner through the deep structure.

Parsing is done via recursive descent. FORTRAN can be a tough language to



parse due to its lack of reserved words and the difficulty of identifying tokens. (Remember the old story about the *DO* loop that allegedly led to a missile mishap, wherein the *DO* loop was supposed to be *DO 100 I=1,20* and was entered as *DO 100 I=1.20*. The latter is an assignment statement, not a *DO* loop.)

The KBSF parser constructs a tree using the FORTRAN syntax and some semantic additions. Consider a parser encountering a FORTRAN name and parenthesized list. Is this an array variable, function call, or possibly a procedure call? We place the name into the tree as a *vrbl* and then use later context and other information to determine its actual purpose.

An Ada package called FORTRAN is used to add Ada features normally found in FORTRAN, including *SQRT* and *COMPLEX*.

Ada generally discourages the use of global *Common* (for a series of good reasons), but many FORTRAN programs make extensive use of *Common*. To adhere to our philosophy regarding FORTRAN-to-Ada conversion, we use Ada packages to handle the *Common* feature.

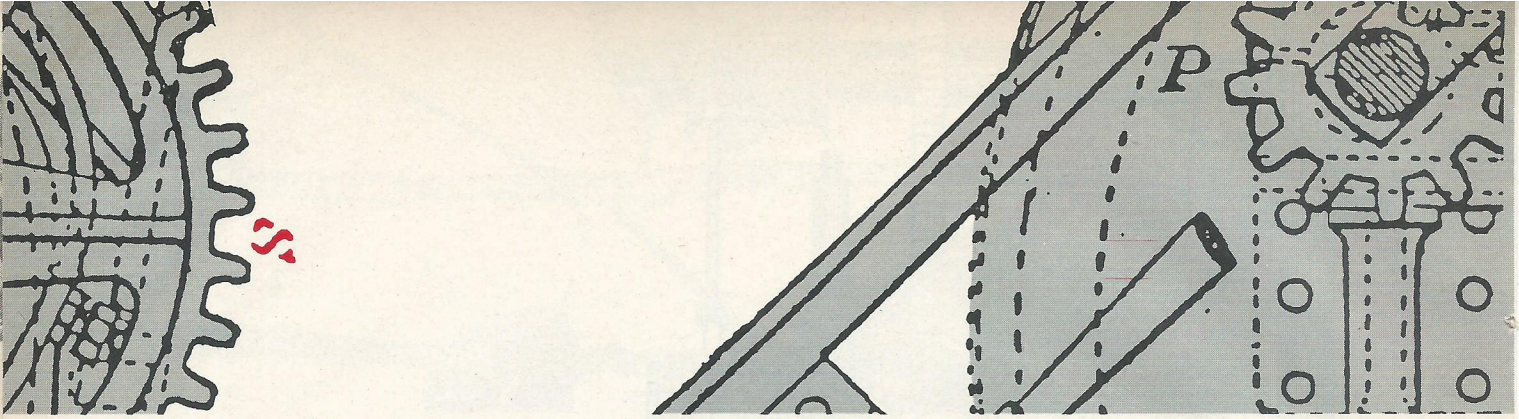
FORTRAN subroutines become li-

```
Sample FORTRAN base illustrating GOTOs

            program gotos
            integer x, y
            if (x .ne. 1) goto 100
              y=1
            goto 500
100         if (x .ne. 2) goto 200
              y=2
            goto 500
200         if (x .ne. 3) goto 300
            if (y .ne. 0 .and. y .ne. 3) goto 250
            z=0
            goto 270
250         z=y
270         y=3
            goto 500
300         if (x .ne. 4) goto 400
              y=4
            goto 500
400         y=x
500         continue
            if (x .ne. 5) goto 600
            y=5
600         stop
            end
            subroutine more
            if (x .eq. 0) goto 20
              y=y+1
              goto 30
20            y=y-1
              if (y .eq. 0) goto 25
                z=1.
                return
25              z=-1.
                return
30          return
            end
```

Listing 2A.

```
Sample Ada conversion generated from 2A

  -- The main program is:
  with FORTRAN; use FORTRAN;
           procedure GOTOS;

  -- The procedures and functions are:
  with FORTRAN; use FORTRAN;
           procedure MORE;

  with TEXT_IO;
  procedure GOTOS is -- main program
    X : INTEGER;
    Y : INTEGER;
    Z : FLOAT;
  begin
    if X=1 then
      Y := 1;
    else
      if X=2 then
        Y := 2;
      else
        if X=3 then
          if Y=0 or Y=3 then
            Z := FLOAT(0);
          else
            Z := FLOAT(Y);
          end if;
          Y := 3;
        else
          if X=4 then
           Y := 4;
          else
           Y := X;
          end if;
        end if;
      end if;
    end if;
    null;
    if X=5 then
      Y := 5;
    end if;
    raise FORTRAN_STOP;
  exception
  when FORTRAN_STOP =>
    TEXT_IO.PUT_LINE("FORTRAN STOP");
  end GOTOS;
  with TEXT_IO;
  procedure MORE is
    X : FLOAT;
    Y : FLOAT;
    Z : FLOAT;
  begin
    if X/=0 then
      Y := Y+1;
      else
      Y := Y-1;
      if Y/=0 then
        Z := 1.0;
        return;
      else
        Z := -1.0;
        return;
      end if;
    end if;
    return;
  end MORE;
```

Listing 2B.



brary-level Ada procedures; FORTRAN functions become library-level Ada functions. In certain cases an additional package is required, and *Use* in Ada attaches the rest of the converted function or subroutine.

Both for clarity and necessity, the Ada target contains a handy set of specifications preceding the body of the subprograms. Furthermore, a *With* clause is needed at the beginning of each subprogram body. Again, it is necessary for Ada and also helpful since it identifies subprograms actually referenced.

Additional details

Brevity here prevents our describing all the converter's details. Basically, the converter is concerned with *Common* and *Equivalence,* parameter modes, arrays, allocating variables, control stuctures (including labels, *GOTO, IF,* etc.), expressions, error handling, input and output, files, and a myriad of other details.

Let's examine three sample conversions. Listing 1A shows a FORTRAN program that illustrates a simple use of functions. Listing 1B shows the target Ada code produced by the KBSF converter and illustrates the handling of types, functions, and simple control structures.

Listing 2A shows a FORTRAN base that uses *GOTO*s, and Listing 2B contains the new Ada conversion. Notice the changes made to preserve the FORTRAN control paths but also produce a structured Ada eqivalent.

Listing 3A shows a FORTRAN pro-

```
Sample FORTRAN base illustrating
strings

  program chars
  integer names(5)
  text = 'abcd'
  names(3) = 'ef'
  text = names(2)
  i = 12
  end
```

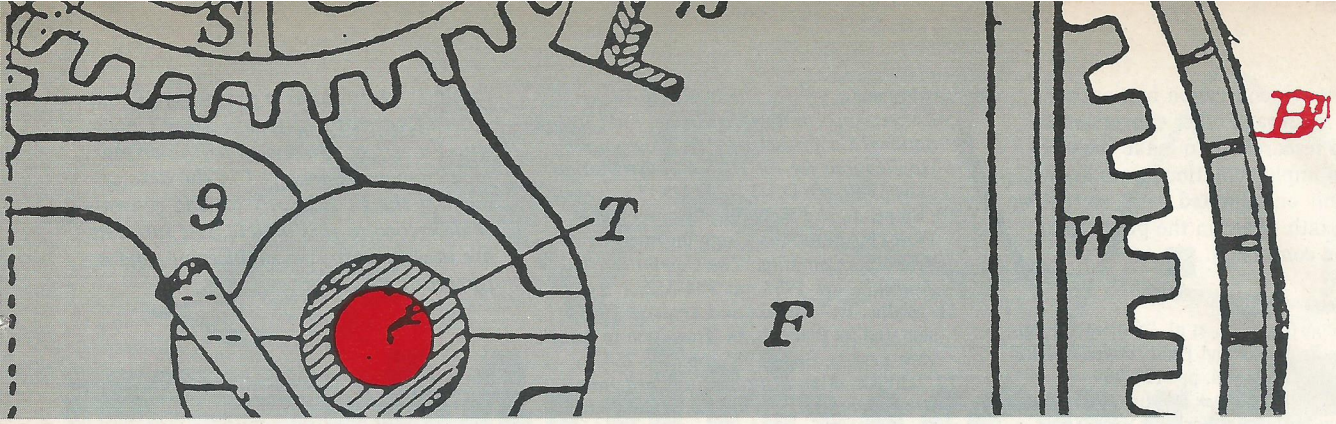
Listing 3A.

```
Sample Ada conversions generated from 3A

  -- The main program is:
  with FORTRAN; use FORTRAN;
          procedure CHARS;

  -- The procedures and functions are:

  with TEXT_IO;
  procedure CHARS is -- main program
    NAMES : array(1..5) of STRING(1..2);
    TEXT : STRING(1..4);
    I : INTEGER;
  begin
    TEXT := "abcd";
    NAMES(3) := "ef";
    TEXT := NAMES(2);
    I := 12;
  exception
  when FORTRAN_STOP =>
    TEXT_IO.PUT_LINE("FORTRAN STOP");
  end CHARS;
```

Listing 3B.

```
Data structure used in the converter

type statement_node (statement_type: statement_types) is
  record
    next_statement: statements:=null;
    label: integer:=0;
    cut_off: boolean:=false;
    comment: comments;
    case  statement_type  is
      when  assignment_statement =>
        lhs:  vrbls:=null;
        rhs:  expressions:=null;
      when  goto_statement =>
        destination: integer;
      when  stop_statement =>
        simple_stop: boolean:=true;
        stop_expression: expressions;
      when  logical_if_statement =>
        condition: expressions;
        consequence: statements:=null;
      when  do_statement =>
        do_end: integer;
        do_index: vrbls;
        m1,m2,m3: expressions;
        do_action: statements:=null;
      when  block_if_statement =>
        block_condition: expressions;
        block_consequence: statements:=null;
        block_else: statements:=null;
        block_elseif: statements:=null;
        block_last_elseif: statements:=null;
        block_falls_through: boolean:=true;
      when  block_elseif_statement =>
        block_elseif_condition: expressions;
        block_elseif_consequence: statements:=null;
      when  call_statement =>
        subprogram: vrbls;
      when  unrecognized_statement =>
        source_length: integer range 0..config.max_source_length;
        source: string(1..config.max_source_length);
      when others =>
        null;
  end case;
end record;
```

Listing 4.



gram involving strings, and Listing 3B shows the Ada eqivalent. Note in the new Ada code that the converter has figured out certain aspects of string usage in the FORTRAN code and produced very matching Ada code.

Listing 4 contains one of the data structures used in the Ada code (part of the deep structure). Listing 5 provides a segment of the converter that scans the FORTRAN source during the first pass. Listing 6 shows part of a segment that emits certain Ada code during the second pass. Listing 7 shows an internal debugging feature built into the converter (to be used by maintainers of the converter).

In principle, the converter can handle most FORTRAN. The design covers all strict FORTRAN, but the current implementation handles typical cases rather than all of the special cases. We have tested the converter with a special set of test cases and are proceeding to test it with live, full-blown FORTRAN programs.

As already briefly mentioned, in a number of subtle instances the converter will confront problematic situations. How is the converter to handle these situations? Our current approach is to have the converter issue warnings and tips regarding the suspected code.

A future approach would be to produce the correct and best possible code. We are beginning to experiment with expert systems technology added into the converter to bring about this goal.

Where it can go from here

We have examined how Ada code is developed, how FORTRAN is converted to Ada, and how code produced by a converter is modified. We hope to distill the rules and inferences exhibited in these explorations into a special converter expert system. Using our current converter, this expert system would work *with* the converter as opposed to replacing it (allowing the converter to do the grunt work and the expert system to take the finer cases).

We have discovered that the adage "FORTRAN programmers will produce FORTRAN-looking Ada code" is often quite true. Just as our converter tends to stick to the FORTRAN base, so do humans rely on their mental base of FORTRAN programs.

Of course there is much more danger in people exhibiting such behavior since they will be developing new code and must perform at levels far beyond the mere act of converting existing old code. We have found that exposing FORTRAN programmers to a converter helps make them more aware of their own biases. And, as might be expected, a programmer perceives the converter to be a piece of automation that can easily be challenged by human skills, thus motivating some FORTRAN programmers to become more Ada-like in producing Ada code.

We urge interested readers to consider how artificial intelligence may help

```
Converter segment from first pass

function parse_statement return boolean is
begin
  debug.note("parse_statement");
  if its_an_assignment and not commas then
    return parse_assignment;
  elsif cursor > length then
    return parse_blank;
  elsif parse("GOTO") then
    return parse_goto;
  elsif parse("STOP") then
    return parse_stop;
  elsif parse("IF(") then
    return parse_if;
    :
    :
    :
  elsif parse_type_name then
    if expecting_statement = title_statement  and then
     parse("FUNCTION")  then
       return parse_function;
    else
       return parse_type_statement;
    end if;
  elsif expecting_statement = title_statement and then
    parse("FUNCTION") then
      result_type:= TBD_type;
      result_star:= Ø;
      return parse_function;
  elsif parse("END") then
    syntax_requires(cursor>length);
    raise end_of_subprogram;
  else
    result_statement:= new statement_node
     (statement_type => unrecognized_statement);
     result_statement.label:= label;
     result_statement.source_length:= length;
     result_statement.source:=image;
    return false;
  end if
end parse_statement;
```

Listing 5.

break through conversion bottlenecks. We also encourage other conversion efforts and researchers to make their designs and implementation issues known, even if only on a limited basis, so that we can all jointly share in the progress toward true conversion.

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We gratefully acknowledge the assistance of Nicholas Baker in the preparation of the FORTRAN-to-Ada converter.

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Floyd L. Holliday is a professor of computer science at California State University, Fullerton. He served as the primary faculty member involved in the development of the FORTRAN-to-Ada converter described in this article. His interests are in Ada, software engineering, and artificial intelligence.


```
Converter segment from second pass

procedure emit_subprogram_preamble is
begin
  emit_new_line;
  emit_indentation; emit("with TEXT_IO;"); emit_new_line;
  emit_subprogram_withs(subprogram_table);
  emit_common_withs(common_table);
end emit_subprogram_preamble;

procedure emit_subprogram_specs is
  s: subprograms:=first_subprogram;
begin
  while s/=null loop
    if s.spelling/=main_subprogram.spelling then
      emit("with FORTRAN; use FORTRAN;"); emit_new_line;
      emit("       ");
      emit_subprogram_specification(s); emit(";"); emit_new_line;
    end if
    s := s.next;
  end loop;
end emit_subprogram_specs;

procedure emit_preamble is
begin
  indentation:= 0;
  emit("-- The main program is:"); emit_new_line;
  emit("with FORTRAN; use FORTRAN;"); emit_new_line;
  emit("       procedure ");
  emit_spelling(main_subprogram.spelling, false);
  emit(";"); emit_new_line; emit_new_line;
  emit("-- The procedure and functions are:"); emit_new_line;
  emit_subprogram_specs;
  emit_new_line;
  emit_common_packages(common_table);
end emit_preamble;
```

Listing 6.

```
Converter segment showing
internal debugging feature

    for i in 1..call_depth loop
      TEXT_IO.put(" ");
    end loop;
    TEXT_IO.put_line("into "&s);
    call_depth:= call_depth + 1;
  end if;
end into;
procedure from(s:string) is
begin
  if debugging then
    call_depth := call_depth-1;
    for i in 1..call_depth loop
      TEXT_IO.put(" ");
    end loop;
    TEXT_IO.put_line("from "&s);
  end if;
end from;
procedure note(s:string) is
begin
  if debugging then
    for i in 1..call_depth loop
      TEXT_IO.put(" ");
    end loop;
    TEXT_IO.put_line("note:"&s);
  end if;
end note;
procedure reset is
begin
  call_depth:= 0;
end reset;

procedure set_file(s:string) is
begin
 if s'length=0 or else s(1)=' ' then
   debugging:= false;
 else
   debugging:= true;
 end if;
end set_file;

end debug;

with TEXT_IO;
package body DEBUG is
  debug_file: string(1..100):=
    (others=>' ');
debugging: boolean:=false;
call_depth: integer:=0;

procedure into(s:string) is
begin
  if debugging then
```

Listing 7.

Artwork: Dwight Been

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Multiway Branching in C

By Alan Filipski

Although the simple *if-then-else* statement provided by most programming languages suffices as a decision control structure for toy textbook problems or theoretical analyses, practical programs often make good use of multiway decision structures that consider more than two alternatives at a time.

An interactive program, for example, is frequently structured as a loop that first reads a command and then takes a multiway branch to decide upon an action. An assembler or disassembler often has many multiway branches for the decoding of assembler mnemonics or op codes. In addition, drivers often have to decode control bytes from external hardware by using such branches.

Multiway branches can be done two ways in the C programming language: with the switch statement or with indexed procedure invocation. The first is a control structure provided by the language; the second is a programming technique allowed by the language.

This article first discusses the switch control structure and how it is handled by typical C compilers. Then the less common technique of indexed procedure invocations is described as an occasionally useful alternative.

Switching in C

In C, the switch control structure for multiway decision making takes the following form:

```
switch ( e ) {
case c1:
   s1
case c2:
   s2
   . . .
   . . .
   . . .
case cn:
   sn
default:
   s
}
```

where *e* is an integer-valued expression, *c1, c2, ..., cn* are constant integer-valued expressions, and *s, s1, s2, ..., sn* represent sequences of statements.

The values of *c1, c2, ..., cn* must all be different. When the switch statement is executed, *e* is evaluated. If its value is equal to one of the constant expressions *ci,* control is transferred to the first statement following the label *case ci*; if its value does not equal any *ci,* control is transferred to the first statement following the special label *default.*

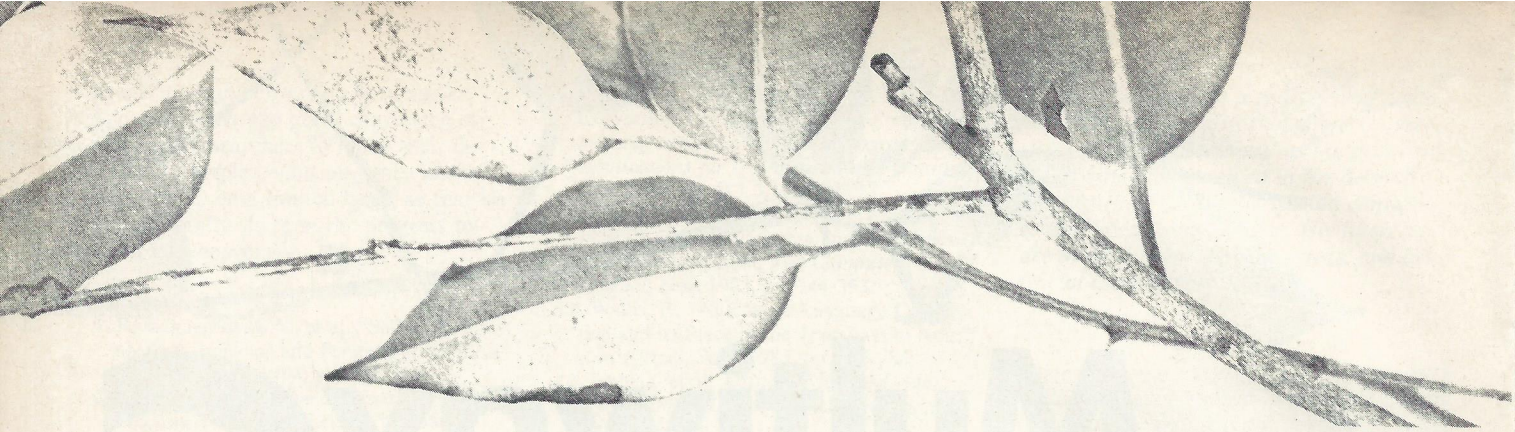
Once control is transferred inside the switch, execution proceeds through all following statements within the switch without regard for subsequent case labels. This situation is usually not desirable, so it is customary to add break statements to jump out of the switch before executing the statements corresponding to the next case:

```
switch ( e ) {
case c1:
   s1
   break;
case c2:
   s2
   break;
   . . .
   . . .
   . . .
case cn:
   sn
   break;
default:
   s
   break;
}
```

To the C programmer, executing the switch appears to consist of evaluating the integer expression and then immediately transferring control to the statement following the appropriate case label. This is an oversimplification. To use the switch intelligently in time-critical applications, it is important to understand how a switch is compiled and what actually happens during execution of the switch.

Most C compilers will compile a switch in different ways, depending upon the number and values of the case constants. For example, consider a case in which the case constants are the consecutive integers 0, 1, 2, and 3 (in all the examples, we will assume there is a break statement after the code for each case):

```
switch ( e ) {
case 0:
   <code for case 0>
   break;
```



```
case 1:
   <code for case 1>
   break;
case 2:
   <code for case 2>
   break;
case 3:
   <code for case 3>
   break;
default:
   <code for default case>
   break;
}
```

A typical C compiler translates this as:

```
   <code to evaluate expression e and
   place result in register, say, r0>
        jump to LA
L0      <code for case 0>
        jump to LB
L1      <code for case 1>
        jump to LB
L2      <code for case 2>
        jump to LB
L3      <code for case 3>
        jump to LB
LD      <code for default case>
        jump to LB
LA      if (r0>3 or r0<0) jump to LD
        jump to address at JTABLE+(4*r0)
JTABLE  L0
        L1
        L2
        L3
LB
```

We are assuming a byte-addressable machine and four-byte addresses, so that *JTABLE+(4*0)* contains *L0*, *JTABLE+(4*1)* contains *L1*, etc.

Listing 1A gives a concrete example of a C switch; Listing 1B gives its translation into Motorola 68010 assembly code (UNIX-style mnemonics). This approach to translation is fairly efficient and straightforward except for one jump (the jump to *LA* in the previous example), which is logically superfluous. If we were coding this by hand, we would move the code:

```
LA      if (r0>3 or r0<0) jump to LD
        jump to address at JTABLE+(4*r0)
JTABLE  L0
        L1
        L2
        L3
```

up to where the jump to *LA* is located and delete the jump.

For a compiler, however, it is easier to defer writing the jump table until all cases have been seen. The extra time taken by the jump is usually not important. The method given may be easily extended by the compiler designer to an offset range of case values by modifying the jump table or the calculation that indexes into the jump table.

For example, if the case values were 500, 501, 503, and 503, the indirect jump would be:

```
jump to address at JTABLE+
  (4*(r0-500))
```

But suppose the switch to be compiled is:

```
switch ( e ) {
case 0:
   <code for case 0>
   break;
case 1:
   <code for case 1>
   break;
case 2:
   <code for case 2>
   break;
case 1000:
   <code for case 1000>
   break;
default:
   <code for default case>
   break;
}
```

```
C program fragment--
dense switch

switch ( eval() )  {

case 0:
   proc0();
   break;

case 1:
   proc1();
   break;

case 2:
   proc2();
   break;

case 3:
   proc3();
   break;

default:
   procd();
   break;
}
```

Listing 1A.

```
Equivalent M68010 code--
dense switch
        jsr     eval
        br      L%39
L%40:
        jsr     proc0
        br      L%38
L%41:
        jsr     proc1
        br      L%38
L%42:
        jsr     proc2
        br      L%38
L%43:
        jsr     proc3
        br      L%38
L%44:
        jsr     procd
        br      L%38
L%39:
        mov.l   &3,%d1
        cmp.l   %d0,%d1
        bhi     L%44
                add.w   %d0,%d0
        mov.w   10(%pc,%d0.w),%d0
        jmp     6(%pc,%d0.w)
        swbeg   &4
L%45:
        short   L%40-L%45
        short   L%41-L%45
        short   L%42-L%45
        short   L%43-L%45
L%38:
L%37:
```

Listing 1B.

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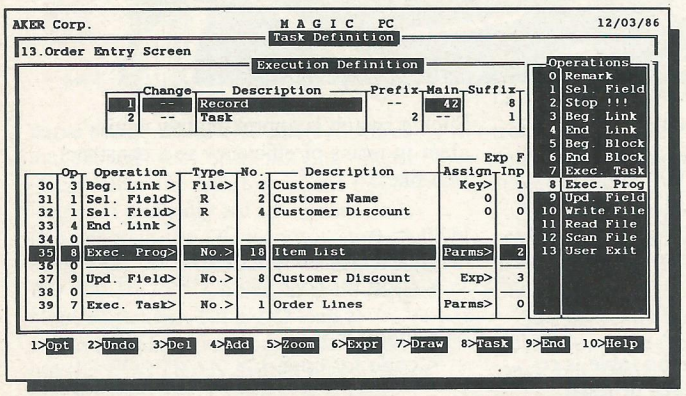

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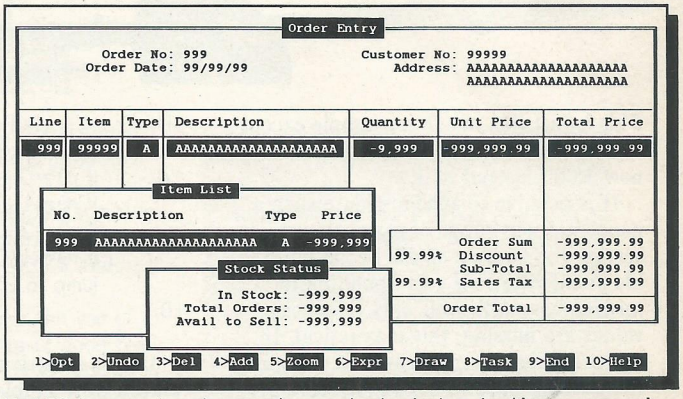

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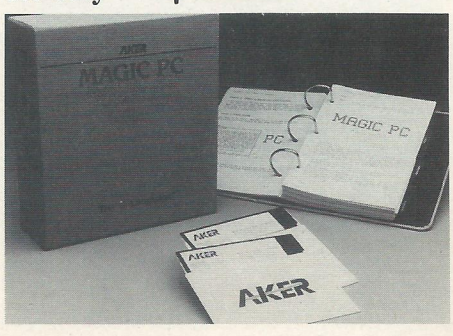

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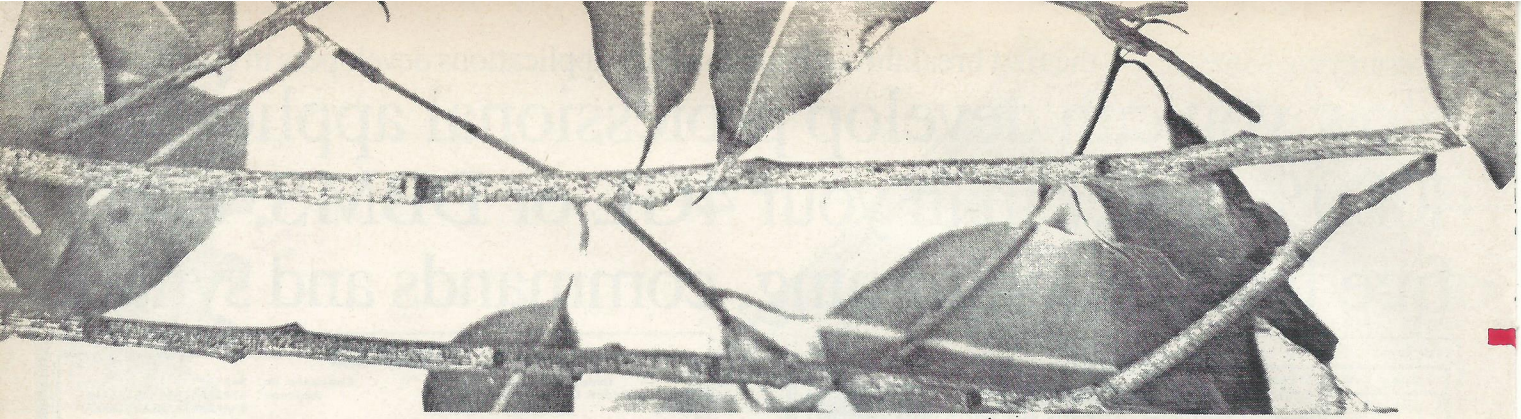

This is just like our first example except that the constant for the fourth case is now 1,000 instead of 3.

It is possible to accommodate such a noncontiguous range of case values by inserting the address of *LD* in the jump table at the locations corresponding to missing case values. If only a few case values are missing, this is practical. In our previous example, however, the jump table would have to contain 1,000 addresses, 997 of which would be the address of *LD*.

To avoid this kind of space inefficiency, most compilers would compile this switch as:

```
    <code to evaluate expression e and
    put the result in register, say, r0>
    jump to LA
L0      <code for case 0>
        jump to LB
L1      <code for case 1>
        jump to LB
L2      <code for case 2>
        jump to LB
L1000   <code for case 1000>
        jump to LB
LD      <code for default case>
        jump to LB
LA      if r0=0 jump to L0
        if r0=1 jump to L1
        if r0=2 jump to L2
        if r0=1000 jump to L1000
        jump to LD
LB
```

In this situation, the jump table is replaced by a simple sequence of tests. Listings 2A and 2B give a concrete example of how this type of C switch would be translated into Motorola 68010 assembly code (UNIX-style mnemonics).

```
C program fragment--
sparse switch

switch ( eval() ) {

case 0:
   proc0();
   break;

case 1:
   proc1();
   break;

case 2:
   proc2();
   break;

case 1000:
   proc1000();
   break;

default:
   procd();
   break;
}
```

Listing 2A.

```
Equivalent M68010 code--
sparse switch

        jsr     eval
        br      L%39
L%40:
        jsr     proc0
        br      L%38
L%41:
        jsr     proc1
        br      L%38
L%42:
        jsr     proc2
        br      L%38
L%43:
        jsr     proc1000
        br      L%38
L%45:
        jsr     procd
        br      L%38
L%39:
        tst.l   %d0
        beq     L%40
        mov.l   &1,%d1
        cmp.l   %d0,%d1
        beq     L%41
        mov.l   &2,%d1
        cmp.l   %d0,%d1
        beq     L%42
        cmp.l   %d0,&1000
        beq     L%43
        br      L%45
L%38:
L%37:
```

Listing 2B.

Such a switch is approximately equivalent in terms of efficiency to a construction like:

```
temp = e;
if(temp==0){
   <code for case 0>
}
else if(temp==1){
   <code for case 1>
}
else if(temp==2){
   <code for case 2>
}
else if(temp==1000){
   <code for case 1000>
}
else{
   <code for default case>
}
```

When programming for maximum efficiency, it is important to realize this distinction: a switch whose set of constant values fills most of its range (such as {0, 1, 2, 3, 5}) is called a dense case statement and may be compiled much more efficiently than a switch with a sparse set of constant values (such as {0, 1, 2, 8761}). Of course, if the switch has only a few constant values and is not executed very often, this does not make much difference. But a nondense switch with many values is quite an inefficient construct.

If the switch is dense except for one value (for example, if the set of constant values is {0, 1, 2, ... 100, 1,000}), for maximum efficiency it may be preferable to split off the 1,000 case with an *if* statement before entering the dense switch.

As a test, I wrote a simple program that executed a switch one million times, with randomly chosen values for the case expression. The switch had 101 cases, each containing very little code. For the first run, the case constant values were the values 1 through 101. The execution time of this test program was 19 seconds on the AT&T PC7300 under the UNIX operating system.

For the second part of the test, the last case constant value was changed from 101 to 1,000. As a result, the execution

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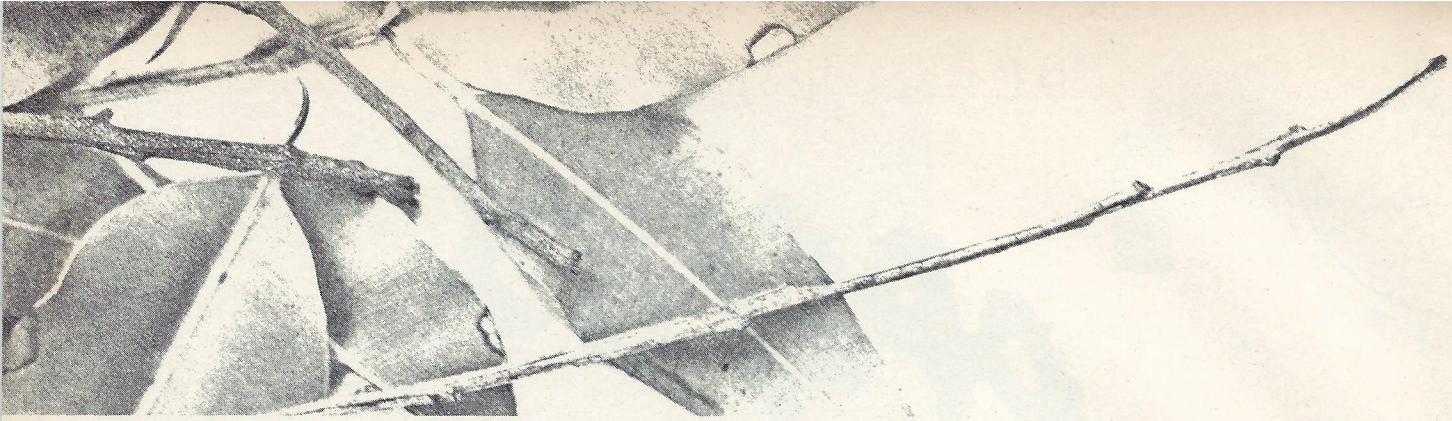

time increased to 30 seconds. This 50% increase in run time was due to the difference between the sparse and the dense paradigms for switch compilation.

A highly optimizing compiler may use other techniques to compile switches. For example, if the set of constant values is nondense and large, the compiler may set up a table in which each entry consists of a constant value and the address of the corresponding case code, and then sort the table by constant value. Then, at execution time, the correct table entry can be found by doing a binary search of that table.

The switch control structure in C provides a natural, easy-to-read way of doing multiway branching in C and can be very efficient, particularly if the programmer is aware of how it is likely to be translated into machine instructions by a compiler.

Invoking indexed procedures

C provides another way of doing multiway branching: indexed procedure invocation. This technique is far less frequently used than the switch and may easily be abused to produce poorly structured code. When carefully used, however, it can provide an elegant solution to some multiway branching problems.

This technique is based on C's ability to compute the address of a procedure, store this address in a data structure, and, finally, call any procedure for which we have such an address.

In C, a procedure name not followed by parentheses is a constant whose value is the address of the named procedure. If we have a variable of the appropriate type, we can assign this address to it.

For example, the variable *x* is declared as *int (*x)();* so that *x* is a pointer to a function that returns an *int* and the C library function *printf* is defined in the usual way as *int printf();*. If we execute the assignment *x=printf;*, then the procedure call *(*x)("hello, world\n");* has an effect equivalent to *printf("hello, world\n");*.

By putting the addresses of several functions into an array, we can select a procedure for execution based on the value of an array index.

Suppose we have defined three C functions, *fun0()*, *fun1()*, and *fun2()*, each of which takes a single integer argument and returns an integer value. We can put the addresses of these three functions into an array, *farray[]*, with the initializing definition:

```
int (*farray[])() = {fun0, fun1, fun2};
```

Suppose we have an integer-valued expression *exp* and want to execute *fun0(arg)* if *exp* is equal to 0, *fun1(arg)* if *exp* is equal to 1, or *fun2(arg)* if *exp* is equal to 2. In every case, we want to return the value from the function into the variable *val*. Then the statement:

```
val=(*farray[exp])(arg);
```

does exactly that. This kind of vectored execution is very efficient and gives the programmer great control, but it is less familiar to many programmers. Listings 3A and 3B give a concrete example of the kind of code generated for this technique by one compiler.

Other techniques?

It is possible to imagine a third kind of multiway transfer: an indexed array of labels, as in ALGOL and PL/I.

Mercifully, the designers of C have not provided programmers with this kind of weapon. The switch control structure, with its forward-only branching, and the indexed array invocation, in which flow control always resumes with the following statement, provide run-time efficiency and readability in a way that should satisfy structured programming purists.

The expert C programmer not only is familiar with these techniques but is aware of how they are implemented by typical compilers.

Alan Filipski has a Ph.D. in computer science from Michigan State University, East Lansing, Mich. He has served on the faculties of Central Michigan University and Arizona State University and was a project leader on the first AT&T certified port of UNIX System V to an M68000 microprocessor. He is currently a member of the technical staff of GTX Corp. in Phoenix, Ariz.

```
C program fragment--indexed procedure invocation

extern int fun0(), fun1(), fun2();
int (*farray[])() = {fun0, fun1, fun2};
int exp;
test()
{
   (*farray[exp])();
}
```

Listing 3A.

```
Equivalent M68010 code--indexed
procedure invocation

farray:
        long    fun0
        long    fun1
        long    fun2

test:   mov.l   exp,%d0
        lsl.l   &2,%d0
        mov.l   &farray,%a1
        mov.l   0(%a1,%d0.l),%a0
        jsr     (%a0)
```

Listing 3B.

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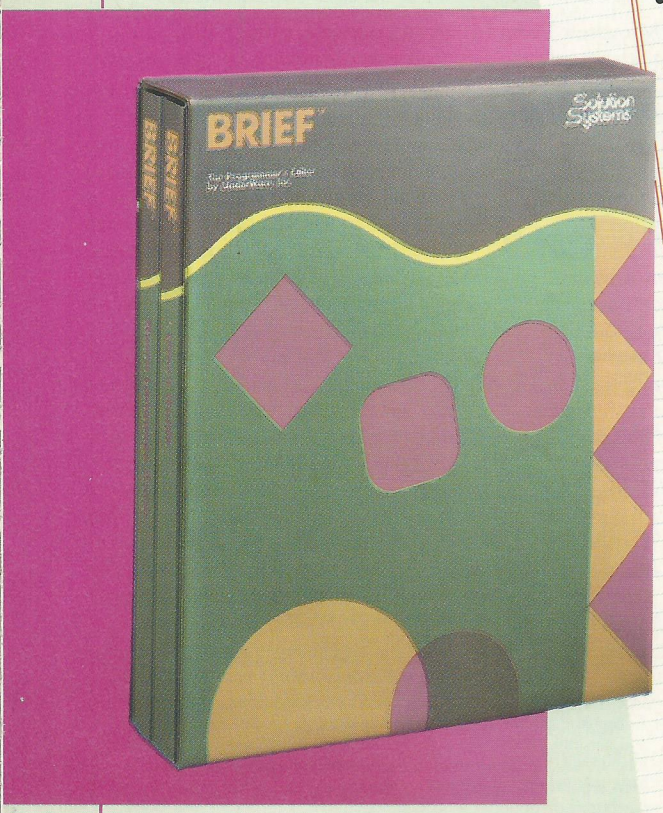

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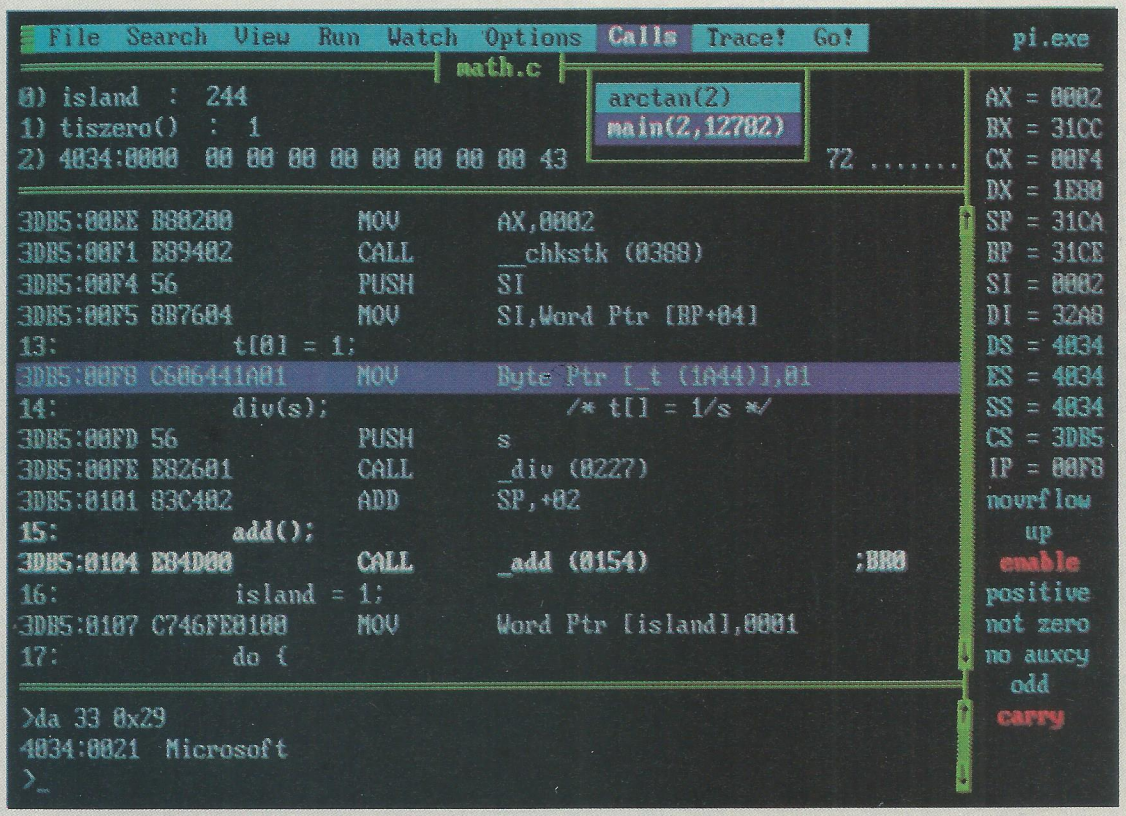

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PUBLIC DOMAIN SOFTWARE REVIEW

Software metrics and EDDY

By Tim Parker

One of the best things about being a public domain columnist is that occasionally a package containing a new program arrives in the mail from a reader or business firm.

Most of the material I've received lately has been of the shareware variety, of which there are two conflicting points of view. The first is that authors are asking for donations while previously they would have simply let it go for free.

The second is that a growing number of products that would have been marketed commercially are now listed as shareware, with the "Try it and if you like it, pay us" philosophy. In these days of expensive software, the latter is definitely a boon to the consumer. The first point of view cannot really be disputed because most authors will spend the extra time to create a package of commercial quality if they can expect some reward for their effort.

Indeed, the last point has been borne out by discussion with many programmers. Take a hypothetical example: I need a routine to do syntax checking on my WHYBOL-47 programming language. Normally I'd hack the thing together with a simple interface, and no menus or help screen and use it as a standard tool in my WHYBOL programmer's toolkit. But I would be tempted to clean up the package and let it go shareware with a donation request if I knew that other programmers were interested in WHYBOL-47, and the only commercially available syntax checker, offered by Fly-By-Night Programming Inc. for $600, wasn't much better than mine.

Even if I request only a $25 donation and 10 people send in the money, the time to write the interface has paid for itself, and my self-esteem and reputation with other programmers have increased.

Now, let's approach the discussion from the other side: as a harried programmer tackling WHYBOL-47 for the first time, and performing under deadline. Instead of paying the $600 to Fly-By-Night, I would get the shareware product from a bulletin board. If it cost me $25, what the heck; I'd still save a fortune, and I wouldn't have to write the code myself.

This example is a little silly and the circumstances are contrived. But the number of shareware users is increasing at a phenomenal rate, and the number of excellent shareware packages is increasing steadily.

Unfortunately, the percentage of users who actually pay for their shareware is small. Two or three thousand people may pick up a typical shareware package off bulletin boards. Normally, fewer than 100 of these people will pay the donation or register their copies. Programmers are not getting rich because of shareware, but they are being compensated somewhat for their time.

I received a particularly interesting disk a short time ago containing two products that made me think of the example just mentioned: METRIC and PCDRAFT, from SET Laboratories Inc., P.O. Box 03963, Portland, Ore. 97203, (503) 289-4758.

One of the packages, METRIC, is very interesting, and I don't think I've seen a similar commercial or public domain release that does quite the same task: it is designed to determine the complexity of a Pascal program.

Software metrics is a relatively new field that is based on a practice programmers have been performing from the start. Software development, especially in a corporate environment, requires a considerable amount of structuring, reporting, estimating, and costing. Software usually has to be cost effective to justify its development and testing time. In addition, modifications are usually required, and it is important that someone who has never seen it before be able to understand the program code. The amount of time and programming effort needed to code a program has always been assumed to be directly related to the complexity of the code itself.

Complexity is measurable in a number of ways. The easiest way is to count the number of decision statements. Although this technique is crude, the more decision statements, the longer (and hence more complex) the code is. This is a poor first approximation, however, as a little thought will show. If a program is constructed modularly, modifications may only be required to a single module while the programmer ignores the rest of the routines.

Further, any code segments that are executed only under certain conditions and are not required for the modifications are ignored. If simple decision structures are used (such as $X=Y$) instead of complicated structures with numerous arguments, the code is easier to read and modify.

The sheer size of a program is easy to determine. If only nonblank lines are considered and all comments are ignored, the number of lines in a program will give a first impression of its complexity. Next, you can get a more accurate idea of a program's complexity by counting the number of tokens in the code. (A 1,000-line program with an average of three words per line is less complex than a 1,000-line program with 20 words per line.)

The number of branching statements will give a first approximation of the complexity of the program control flow. A program with numerous *IF*s, *WHILE*s, and similar structures is more complex than a top-to-bottom program with no branching or flow interruptions.

Altogether, these procedures develop into an assessment of the complexity of the program expressed by a number of variables. By taking these variables into consideration, a program's development time can be estimated. Indeed, literature has shown that these assessments are fairly accurate when a good complexity rating algorithm is used—much more accurate than other estimating routines that are used by development people.

So far the discussion has dealt with determining the complexity of existing programs. If these existing programs can be assessed, it would seem logical that a currently undeveloped program can be placed on the scale of complexity, based

on a person's experience and instinct, to derive a better estimate of the development time than would be possible through simple guesswork.

For those who are interested in software metrics, a short bibliography of references is contained in the accompanying sidebar, "Suggested reading on software metrics."

METRIC, when run against some Pascal source code, uses algorithms to determine the complexity of the code. A discussion of the algorithms and techniques is included with the METRIC program in the documentation file, along with a brief description of the software metric field.

The interface is simple. After a single identification screen, the input file name is requested. The screen then shows the ascending word count and the procedure currently being evaluated. After completion, the program exits and a text file that lists the METRIC output is created.

The output is simple. It lists a number of software metric variable results, which are correlated to the variable's meaning (reference books are best here). A number is produced for the code's volume and effort. A predicted bugs number shows an estimate of the number of errors that can be generated (this is not a syntax check!), and a predicted development time is shown in minutes and hours. A cyclomatic number is also produced, which again requires the user to know a little about software metric theory. The number of lines of code, procedures, and executable semicolons is printed.

The program allows the user to modify the list of words recognized as tokens by METRIC, enabling the system to be customized to different compilers. For example, a Turbo Pascal user can include all the Turbo keywords not included in the token list to get an even more accurate idea of the program complexity.

As a sample, I ran the program FICALCS through METRIC. (I discussed FICALCS several months ago in "Financial calculations and Batch files," *COMPUTER LANGUAGE*, Jan. 1987, pp. 83-85. Written by Roy MacLean, FICALCS is a great financial calculator and a good example of Turbo coding.) METRIC predicted 16 bugs in the finished code.

After I customized the METRIC package to Turbo keywords, the prediction dropped to two (none actually exist in the package: bugs are predicted based on the complexity of the code). The estimated development time was 311 hours, which, according to MacLean, is remarkably close (an actual count wasn't kept, but this seems as good an estimate as is possible). The almost 1,500 lines of code had a purity ratio of 0.51, which does not mean his code is only half pure. (Read the books for an explanation.)

On one of my network programs, designed as an on-line help system, METRIC produced a development time of 120 hours. The actual time was 127. It was remarkably close on several other test program too, although the errors increased as the hours both exceeded 200 and went below 10. Nevertheless, I was amazed at the accuracy of the estimates.

Granted, the information METRIC supplies isn't very useful to the run-of-the-mill programmer who wants to hack out a simple game, but it is to serious software developers. After using the program for a few weeks on random selections of code that are either finished or under development in my library, I got very interested in the subject and followed through the readings in the bibliography. Unconsciously, I found myself coding a little differently, in a more structured and modular way than before.

METRIC is sure to get readers who are interested in software design theory hooked on the field. I was surprised to find that many software development houses do follow the metric field quite intensely, although not always under that name or with the level of complexity that is possible.

METRIC is available on several bulletin boards and directly from SET Laboratories. The author requests a $99 donation if the software is found useful.

I suspect METRIC will have a very limited appeal, but for those who revel in

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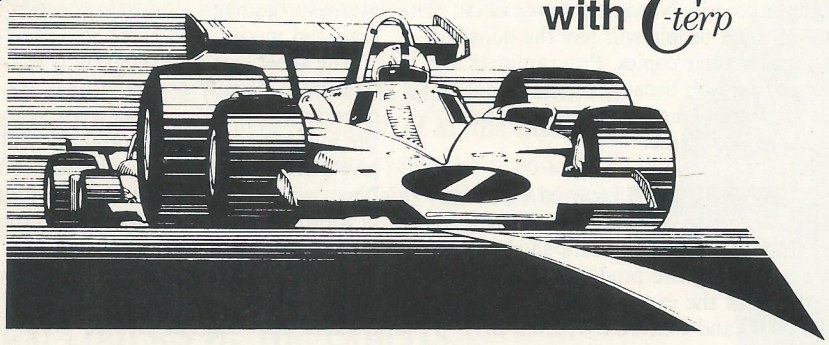

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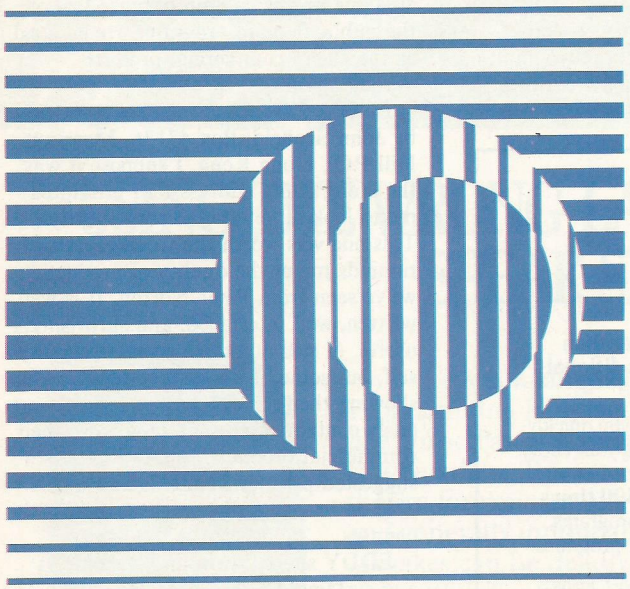

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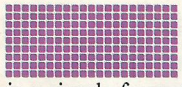
software theory and find themselves in software development cycles, it is an interesting, useful, and innovative program.



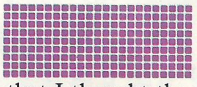
The other product sent to me by SET Laboratories is a simple formatter, similar in many respects to nroff formatters on mainframes and minis. It is worth mentioning because it is one of the few post-processor text formatters I have found that works consistently bug free. It also has a good arsenal of command functions and works fairly quickly.

PCDRAFT commands are all on new lines and begin with a period, like WordStar dot commands. A brief list of the functions supported includes page eject, centering, line spacing, page forcing, display text, footers, headers, item lists, auto indent, margin settings, page number changing and printing, page length, autoindent on paragraphs, section headers, and underlining.

Although many people prefer word processors to text formatters, when the need for a test formatter arises, I find PCDRAFT to be very useful. Its command set is complete enough to allow all the formatting normally required, and it has a handy automatic table of contents generator that is based on sections titles.

I found I could port files without modifying them from the local university Amdahl to my PC and back using PCDRAFT and a modified version of vroff on the mainframe, thereby simplifying documentation on some mainframe code I am writing. Since word processors are still scarce on mainframes and many minis, ASCII files and text processors are de rigeur in that environment. Although not true of micros, it is necessary to use these postprocessor text formatters when working in both environments, and PCDRAFT is a good one.

SET Laboratories requests a $20 donation if PCDRAFT is found useful.



I have seen so many disk directory utilities over the years, that I thought the market was saturated. I was wrong. I also thought I'd never discuss one in this column because few of the public domain programs are as good as the cheap commercial products. Wrong again!

EDDY (EDit DirectorY) was written by John Scofield, Box 47136, Morrison Hill P.O., Hong Kong. I suppose it was the Hong Kong address that prompted me to look at yet another disk utility. This one was worth the trouble. EDDY reminds me of the quality of product we've seen from Peter Norton. It is well written, well interfaced, and surprisingly useful. (I still don't use an interface myself, but some of my colleagues do. After showing them EDDY, a couple have seriously contemplated switching from their commercial products.) EDDY carries a suggested price of $15. It is also available on several bulletin boards across the country.

EDDY should work on all monitors and systems. I tested it on Hercules, CGA, MDA, and EGA. A command line parameter optimizes monochrome operation.

The interface, as mentioned, is elegant. Reverse video is used where necessary, and a very good on-line help file is available with the F1 key.

One very nice feature EDDY has that others don't is *UNDO*. Suppose you've just renamed files, changing their attributes, and then realized you'd made a mistake. One keystroke undoes it all. Date, time, file name, file type, and attributes can all be edited. The interface uses the "Put the cursor where it has to go and type" approach, allowing fast entry. (It worked with my mouse.) I found the interface particularly useful for changing file attributes.

All the major commands are available on function keys listed at the bottom of the screen. A summary of the commands not listed on the bottom line is available through the help screens.

The *delete* function works as expected, but there is a similar function called *destroy*. This function not only deletes but overwrites the data on the occupied clusters, preventing recovery with one of the superutilities like Mace or Norton.

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so I will not discuss them. The program can check to see that programs moving across directories do not conflict with existing file names. Also available are several command line options that control copying and date and time stamping, depending on the user's requirements.

A patch command changes a file's contents, in either hex or ASCII. Conversion between the two formats is fast. Changes are not written to the file until an *UPDATE* command is executed, to prevent an error from occurring during the patch process. The *UNDO* feature is available to get rid of bad changes.

EDDY comes with a 37-page documentation file that describes the program and its capabilities completely. Overall, I found EDDY to be a clean, easy-to-use, well-written program. John Scofield has done a good job here. ■

Tim Parker is a systems programmer in Ontario, Canada who also writes for several technical magazines.

Suggested reading on software metrics

Elements of Software Science. M. Halstead, New York: Elsevier North Holland, 1977.

"Applying Software Metrics to Program Maintenance." *IEEE Computer.* W. Harrison, et al. (Sept. 1982):65-79.

"A Complexity Measure." *IEEE Transactions on Software Engineering.* T. McCabe (Dec. 1976):308-320.

"Defining Software Science Counting Strategies." *ACM SIGPLAN Notices.* N. Salt (March 1982):58-67.

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DESIGNING WITH DATA BASES

Fidelity and the full relational model

By Matthew Rapaport

Back in March, I began by listing 14 qualities, cited by James Martin, that make a language fourth generation. Since that time, this column has focused on the third element of Martin's list: possession of an inherent data management system.

In April we discussed some general data models and the ANSI Standard Planning and Requirements Committee (SPARC) three-schema architecture ("DBMSs in the real world," *COMPUTER LANGUAGE*, pp. 95-100). E.F. Codd's relational model[1] was the source for the examples and illustrations in our discussion of directories and data dictionaries ("Directory and dictionary components," *COMPUTER LANGUAGE*, May 1987, pp. 79-84), and integrity issues ("Data base integrity," *COMPUTER LANGUAGE*, June 1987, pp. 87-94).

Some of the integrity issues we've discussed (like the entity and referential integrity rules) apply only to relational systems, while others (for example the concept of *DOMAINS*) can be usefully applied to hierarchical, network, and other data models.

I did, however, address these subjects from a relational viewpoint because most DBMS products in either small (micro) or medium-size (multiuser micro and mini) computer systems claim to be relational. The only exception I know of (and I am including here only those products that manage multiple files/tables at the same time) is Micro Data Base Systems' MDBS III, a powerful, package based on the CODASYL network model.

DBMSs have been around much longer than fourth generation languages. I have addressed only a few DBMS design and usage aspects, and I will explore these and other issues again as we discuss using DBMS and fourth generation products in application development in a more formal way. I will also briefly discuss other aspects of the fourth generation language environment: procedural and nonprocedural languages, screen and report generators, and styles of integration between various components. First, however, let's evaluate some of the popular products on the market using Codd's criterion for a relational DBMS.

In October of 1985, articles written by Codd appeared in two consecutive issues of *Computerworld*.[2,3] In these articles he delineated 12 rules, 18 manipulation features, nine structural features, and three integrity features that make a DBMS fully relational.

In these now famous articles, Codd compared three well-known mainframe-based DBMSs for compliance with these rules. Few of us have to decide whether to buy IBM's Information Management System or Cullinet, products which cost around a quarter of a million dollars. More likely, we may choose between Ashton-Tate's dBASE, Microrim's R:base, Unify Corp.'s UNIFY, Informix Software's Informix, and other micro or super-micro based products. I will therefore review Codd's rules and attempt to apply a variation of his qualification scheme to the products I have been using as examples.

We find that compliance with the rules as a whole does not necessarily mean a product is fit or unfit for any given DBMS application. Different applications are best met by tools with strengths in areas that are important to a particular use, even if they are in other areas.

In the last issue, I alluded to a general difference between management information systems (MIS) and Data Processing (DP) applications. This distinction, along with others such as the scope of a given application, strongly influence product choice. I will look at these differences in some detail, bearing in mind that the degree of compliance with Codd's rules is only one factor in the decision to commit development to a particular DBMS.

To be minimally relational, a DBMS must explicitly represent data in tables and not require that any data be embodied in pointers, links, or ordering. A second requirement is for the data manipulation language (DML) to support the basic relational operations of projection, selection, and one of several kinds of join operations.

Products that do not support both of these requirements may be relational like, but not true relational data bases. As we shall see, many of the most popular DBMSs do not meet both of these criterion. Often their failure is due to an implicit consequence of the minimalist rules we shall explore later. But first, the rules.

1. Information rule. All data in the data base is represented explicitly as values in tables (not in links, pointers, or ordering). This rule is the basic foundation of the relational model, and the first part of the minimal rule.

2. Guaranteed access rule. Every datum in the data base is guaranteed to be accessible through its own primary key. This rule is also part of the relational model's foundation. Supporting techniques vary widely among products. Ideally, key uniqueness is supported at the data dictionary or directory level of the DBMS and not through indexes, though the latter will satisfy the rule if they cannot be subverted—access must be forced through the index for all kinds of applications and languages that can utilize the data.

3. Systematic treatment of *NULL* values. This seemingly innocuous rule has spawned a body of DBMS theory.[4-6] The underlying problem is that the nonexistence of something is impossible to represent by the presence of some marker that does exist without potential contradictions.

For example, consider an employee whose skills are unknown, represented by the presence of N/A (Not Applicable) or a question mark (?) in the skill attribute position. It is difficult to find a single way to handle all possible variations of a query like "Show me everyone who has skill *X*" and "Show me everyone who does not have skill *X*" and always produce meaningful answers. Sometimes we want nulls to be counted as belonging to a select set, and other times we do not.

Compliance with this rule is often found in extensions to the DBMS query language such that the user can switch the different senses of *NULL* on or off.

4. Dynamic on-line catalog rule. The

data base dictionary that describes the data must also represent its metadata in tabular format with all of the integrity and manipulative characteristics of the data base as a whole. This means that the dictionary can be created, queried, and updated with the same DML as the data itself.

5. Comprehensive data sublanguage. Whatever languages the DBMS may support, there must be at least one language whose statements are expressible as formally specified strings and that supports all of the following:

- Data definition (creating base relations)
- View definition (external views)
- Data manipulation (select, project, and join)
- Establishing integrity constraints
- Establishing security barriers
- Delineating transaction boundaries (begin, commit, and rollback).

Part of this rule comprises the second half of the minimalist rule. Products that seemingly fail the minimalist rule often do so because they do not support true joins at the set level. Otherwise powerful products like Cosmos' Revelation and DataAccess Corp.'s DataFlex do not support an operation that logically joins two tables to create a third table. While many of the products mentioned in this column do support this operation, most of these products would fail the other requirements of rule 5.

6. View-updating rule. This rule states that the system can update any view that theoretically can be updated. A view can be updated if a time-independent algorithm changes the view in precisely the desired way when applied to the base relations that compose that view.

Here, update also refers to inserts and deletes. This is not a trivial feat, as you can see if you look back at Figure 2 in my April column. If, for example, the address of Customer 1 in the left-most base table were to change, four tuples in the external view would instantly have to reflect this change to whatever application software happened to be using it at the moment.

7. High-level language rule. The comprehensive data sublanguage specified in rule 5 must also be able to handle both base and derived relations as single operands, that is, sets of rows in a single operation involving either retrieval, insertion, or updating of data. The dBASE statement: *REPLACE ALL AMOUNT.DUE WITH AMOUNT .DUE*1.05 WHERE DAYS.DUE > 90* is a typical example of the use of this kind of high-level language statement. This statement produces a new relation: *(ALL TUPLES WITH DAYS.DUE > 90)* and, from the user's perspective, performs a single operation at the same time.

8. Physical data independence. This rule demands that applications code using a DBMS remain logically unimpaired if physical changes are made to the files that constitute the data base. Such changes include moving a file from one disk volume to another, splitting a large file into two or more files, physically joining two files into one, changing the data structure of a physical file, or any performance alterations (sorting, setting up new indexes, recreating hash tables, and other operations not typically available to micro-based developers).

This rule does not insist that such applications be immediately usable after physical file changes (recompilation may be required, for example), only that their logic not be compromised by physical alterations to accessed files.

One of the primary reasons for the development of DBMS systems was to satisfy this rule. The rule is usually waived during an attribute deletion, but it is possible to envision ways to automatically shield applications logic from deletions. To date, no product supports automatic delete protection.

9. Logical data independence. Like rule 8, this rule applies to the logic of applications software, which should remain unimpaired by changes to the conceptual level of the data base (see my April column for a discussion of architectures). Such changes include splitting a relation in two, joining two or more relations, adding attributes, and any other changes that theoretically permit unimpairment.

Again, deleting an attribute is outside this requirement, as are operations like changing attribute lengths or data types. These changes may or may not accompany physical changes to the data files. Note also that this rule is more restricted

Codd's relational criteria

Structural features

S1. Relations of assorted degrees. Tables with various numbers of attributes, unnumbered rows (no meaning in order), no positional concepts, named columns, and no repeating groups.

S2. Data wholly represented in tables.

S3. The result of a query is another table, which may be treated like any other table—a query table.

S4. View, or virtual, tables. External views that have internal representation in the commands and definitions that create them but do not store any data.

S5. Snapshot tables, evaluated (created) and stored along with some directory entry indicating the date and time of creation.

S6. Every column of every table is an attribute—no pointers per se.

S7. Each attribute obtains its values from a real domain.

S8. In each row, there is at least one combination of attributes whose values identify that row unambiguously—a primary key.

S9. Attributes can reference each other by meaning. This occurs when an attribute in one table is on the same domain as the primary key of another table. A foreign key can be thought of as an ambassador from the head-of-state (primary key) in one relation to some other relation.

Integrity features

I1. Entity integrity (covered at some length in last month's column).

I2. Referential integrity (also discussed last month).

I3. User-defined integrity. Essentially, the other mechanisms involved in what I termed class 1 integrity issues in "DBMSs in the real world," *COMPUTER LANGUAGE*, April 1987, pp. 95-100. These include masks, range tests, triggered procedures, and enumerated types.

Manipulative features

M1. Theta select
M2. Project
M3. Theta join
M4. Outer theta join
M5. Divide
M6. Union
M7. Intersection
M8. Set difference
M9. Outer union
M10. Relational assignment
M11. Theta select maybe
M12. Theta join maybe
M13. Outer theta join maybe
M14. Divide maybe
M15. Theta select semantic override (s/o)
M16. Theta join s/o
M17. Outer theta join s/o
M18. Divide s/o

Theta refers to the algebraic operations >, <, =, <>, etc. The maybes and the semantic override are extensions made necessary by the problems arising from the need to treat *NULLS*.

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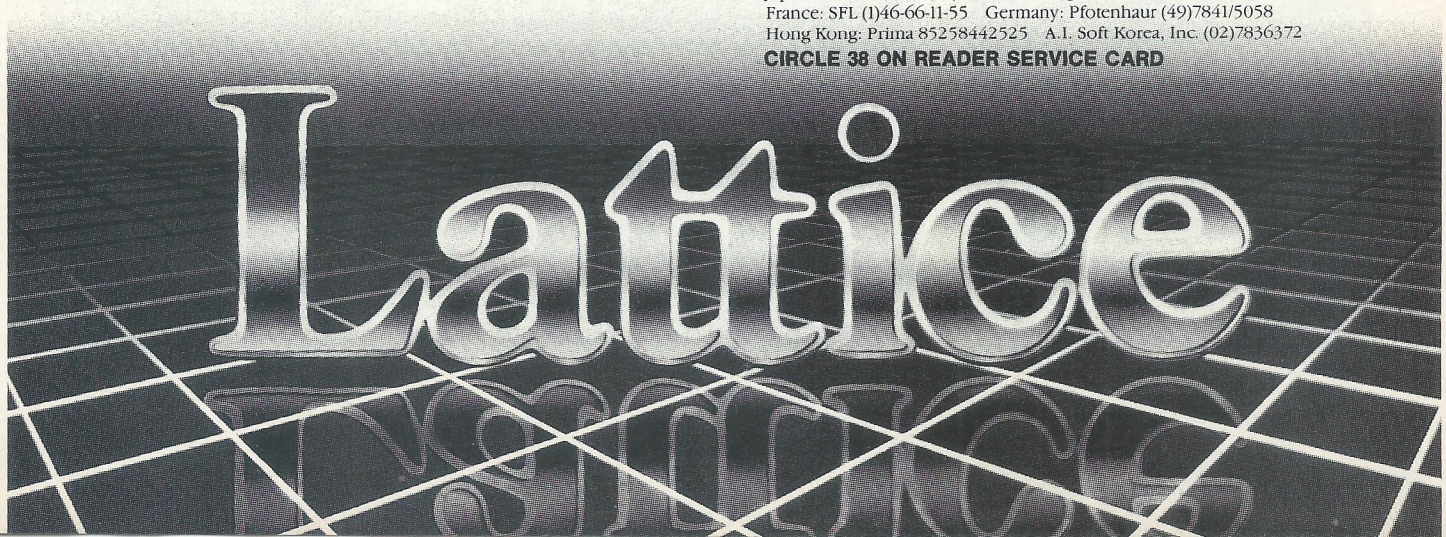

than rule 8, which does not qualify a class of changes to which the rule applies.

Where physical files are concerned, any change (except deletion) should remain invisible to the application program (and, by implication, to the conceptual schema). However, the conceptual level is one step nearer the application, and applications logic becomes sensitive to a broader class of alterations.

The inability of early data models to support this feature was one of the reasons for the development of the relational model. But even a DBMS that is relational in the sense that it supports tables and references by meaning will fail this requirement unless it also supports external views that can be updated.

External views are the third schema of the ANSI SPARC architecture. Codd appears to have anticipated the findings of ANSI SPARC in demanding that view support (rule 6) be included in the full concept of the relational model.

10. Integrity independence. A substantial portion of my last column was spent on part of this rule, which includes both entity and referential integrity rules. The entity integrity rule imposes strict format standards on primary keys of relations.

Specifically, each key must be unique, indentifying each tuple in a relation purely by reference, without regard to pointers, offsets, or information embodied in any formal link.

Second, every component of the key must be necessary to establish this uniqueness when the relation is seen as a whole.

The referential rule extends the power of the entity rule to all the relations of a data base. Each time the primary key domain of one relation is named in an attribute of another relation, or foreign key, (as when the *employee* relation names the *job* relation with the attribute *job.number*) that particular key must already exist in the set of primary keys actually in the named relation. This ensures that only one tuple will be returned when one relation points (by reference) at another. It also indirectly guarantees that every tuple in the data base is not only accessible without use of traditional pointers, but that no foreign key misleads by referencing a primary key (and tuple) that doesn't exist.

More than this though, Codd specifies that whatever kinds of integrity constraints are applied to data, they must be specifiable in the data sublanguage of rule 5 and be storable in the system catalog (the directory/dictionary), not in applications software. Since there are many integrity constraints, no product can satisfy this rule (even if it supports entity and referential integrity at the directory level) unless it has a dictionary of uncommon power.

11. Distribution independence. Like the physical independence rule, distribution independence requires that applications programs remain logically unimpaired if the physical files of the DBMS become distributed across multiple CPUs. It is not necessary that a particular product actually support distributed data bases to qualify under this rule, only that their associated data manipulation language theoretically be able to function unimpaired if the data could be distributed.

12. Nonsubversion. This last rule deals with various language systems that may be able to access and update data. It states that the controlling DBMS must not permit any interface that can subvert the integrity protection provided by the DBMS to the attributes of any relation.

This protection extends to all attributes in their respective domains and is especially important to primary and foreign keys. A COBOL program cannot be allowed to place a value in a foreign key if that value does not already exist in the relation to which the key refers. A BASIC program cannot put a string like *4153971881* in an attribute if the format of that attribute is supposed to be *(999) 999-9999*.

Obviously, this rule cannot be supported if the data dictionary does not directly control most of the integrity checking.

* Besides the 12 main rules, Codd delineated nine structural, 18 manipulative, and three integrity features that must all be supported fully for a DBMS to claim full fidelity to the relational model. He combined these features and rules, 42 in all, and gave each product one point for each rule or feature it fully supported. Doubling the resultant score yields an approximate fidelity percentage, and Codd recommended that this figure be rounded to the nearest significant 10%. The highest score was 46 (roughly 50%) for

Rule features

Features	Related rules
S1	
S2	1
S6	
S3	
S4	6
S5	
S7	See manipulation group
S8	
S9	2, 10
M1 ⋮ M14 ⋮ M18	3, S7 → 7
I1	
I2	10
I3	

Codd's 30 features in association with their corresponding rules.

Table 1.

Rating products by Codd's rules

Products	Rules 1 Information	2 Access	3 Nulls	4 Dictionary	5 Data sublanguage	6 Views	7 HLL	8 Physical indep.	9 Logical indep.	10 Integrity	11 Distributive indep.	12 Non-subversion	T	%
dBase III+	2	2	0	0	1	2	2	0	0	0	0	0	9	38
R:base Sys. V	2	2	0	0	0	2	2	0	1	1	0	2	12	50
Revelation	2	2	0	2	0	0	0	0	0	2	0	0	8	33
Supra	2	2	0	1	0	2	1	2	2	1	2	2	17	71
Unify	2	2	0	0	0	0	2	1	0	2	2	1	11	46
Informix	2	2	2	0	2	2	2	1	1	0	2	0	16	67
Dataflex	2	2	2	0	0	0	0	1	0	0	2	0	9	38
Paradox	2	2	0	1	0	1	1	0	0	1	0	2	10	42
Nomad 2	2	2	0	0	0	0	2	1	1	2	0	0	10	42

A "0" indicates no support for the corresponding rule. A "1" indicates partial support in one form or another, while a "2" signifies relatively full support for the rule.
Factor = 4.17.

Table 2.

IBM's DB2.

Codd's approach to the ratings is not as informative as it could be. The 30 extra features have varying degrees of relation to the 12 main rules. Sometimes two or more features comprise the essence of a main rule, other times they extend but do not replace the main rules. The rules are unevenly represented in the features; some associate with many features, others with few or none, and one of the features is not clearly associated with any rule.

The accompanying sidebar, "Codd's relational criteria," sketches the 30 features. I will look at these in greater detail next month. Table 1 groups the features by the rules they seem to fit best.

Because some products seem to partially support some of the rules, I thought it appropriate to provide a category of partial qualification. Support for each of the rules is scored with a 0 for no support, 1 for partial support and 2 for full support. The results of some of the well-known products are shown in Table 2. The best possible score is be 120, so I scaled each of the scores by 4.17 to derive the percentage figures shown in the right-most column.

The evaluation presented in Table 2 is arguable because partial qualification (a score of 1) depends upon my observation that a product satisfies some but not all parts of a given rule. Partial support does not imply that a product supports half of a rule's implications, only that it does not satisfy the rule fully but obviously contains some support.

In the next issue we will analyze these rules in association with the features and discuss the value of this analysis in the selection of a DBMS product for real applications.

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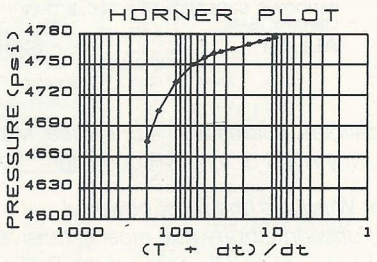

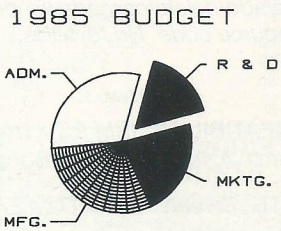

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Knowledge representation with CRL

By Doug Schuler

The description of reality has long challenged mankind. The conceptual metamorphosis that occurs from perception of the real world to a description, knowledge, or an efficient yet natural representation of knowledge in software is essentially a philosophical pursuit. Nevertheless, demands from the real world create an acute need for an approximate solution. In this modern age, knowledge representation is a central concern of artificial intelligence research. AI research is a quest for appropriate representations of complex objects and appropriate means of utilizing those representations.

Computer scientists and programmers must serve two masters. They must represent knowledge in a way that is sensible to users and to computers. Knowledge representation is an important concept for programmers of conventional software as well as AI programmers. Knowledge representation is an important component of present AI tools and will likely be introduced into conventional programming. Moreover, understanding the concepts of knowledge representation would be helpful to understanding the semantics of complicated knowledge in conventional programming.

Many researchers believe that the key to knowledge representation in computer software lies in the ability to gather attributes into a small set of similar objects that are manipulated with a small set of operations. One of the earliest developments in representing world knowledge in a flexible data structure for a computer was Marvin Minsky's concept of frames in 1975.[1] A frame is a data structure having some similarities to a Pascal record that possesses slots and values. Frames are differentiated from records by the variety of values, including functions, that slots can hold. Frames can also be connected into frame systems when other frames are referenced in slot values.

For example, a frame called *dog*, in which the pertinent attributes of a dog are stored, can have a slot called *ISA* and a value of *MAMMAL*. Values can be propagated or inherited throughout the frame system. In the dog example, a dog may inherit *WARMBLOODEDNESS* from the mammal frame. Frames are also used in a generic sense to describe similar data structures in various systems, such as schemas in the Carnegie Representation Language (CRL) or units in Intellicorp's Knowledge Engineering Environment (KEE).

Frames and framelike constructs are currently providing the foundation for much AI work. This research is often manifested in the development of representation languages. Earlier work in this field includes that of T. Winograd,[2] B. Kuipers,[3] and the Frame Representation Language group at the Massachusetts Institute of Technology, Cambridge, Mass.[4] Douglas Lenat and other researchers at Microelectronics and Computer Technology Institute are using frames in the CYC project,[5] an ambitious effort to represent all the knowledge found in a standard desk encyclopedia.

CRL is a frame language derived from the Schema Representation Language. SRL was developed at Carnegie-Mellon University, Pittsburgh, Pa.[6] for use in AI applications such as process planning and engineering project management.

CRL is the underlying glue of Knowledge Craft, a commercial product available from Carnegie Group Inc. for development of knowledge-based systems. Knowledge Craft is a sophisticated AI program development environment for industrial, financial, and other applications. Knowledge Craft provides a user-friendly interface to the system's schemas and capabilities, including editors and graphic representations of the system. Forward-chaining and backchaining languages (OPS-5 and PROLOG), object-oriented programming, demons, and event-driven programming are all supported. Knowledge Craft is an integrated collection of tools for knowledge-based programming in the same family as KEE and Inference Corp.'s ART. Although CRL is copyrighted by Carnegie Group Inc., it is basically the same as SRL, which is in the public domain. Therefore, many of my comments apply to both languages.

CRL should be used as a tool for solving problems that are not easily addressed through conventional programming. These problems include problem domains that are interrelated in complex ways and whose relations may change. CRL should be used if the solution to the problem seems just out of reach of conventional programming.

A frame in CRL is called a schema. CRL is essentially a collection of functions, written in Common LISP, that are used to create, modify, relate, test, and delete schemas, slots, and values. These schemas are related via relations and together form networks of knowledge. Let's look at a specific example to demonstrate these features.

For several years I have wanted a program that would help me decide what to do based on my assigned tasks and considering my current resources. I didn't want a machine telling me what to do—just one that would remember pertinent information and make intelligent suggestions. The program would do some scheduling, provide meaningful defaults, and have an acceptable user interface for entering, viewing, recording, and purging things to do. Of course, I would reserve the right to ignore its advice and do something else if I felt like it.

It seems clear that at the core of a Things-to-Do Advisor there must be a representation of a thing to do. We will start our system by defining one of these. The CRL function *CREATE-SCHEMA*, written in LISP, is used to create a schema called *THING-TO-DO*. When the schema is created, the name is returned:

```
> (CREATE-SCHEMA 'THING-TO-DO)
THING-TO-DO
```

Next, let's create some slots in the THING-TO-DO schema (Listing 1).

Presumably, any *THING-TO-DO* would have a priority, location where the task could be accomplished, due date, and resource requirements. A *FUN* slot would also be useful. If tasks G0001 and G0002 were identical, except that task G0001 was more fun, why not do G0001 first and let G0002 go until another day?

Now that a schema and some slots exist, let's add some values to the slots (Listing 2). These values will be used as defaults—that is, the values in the slots will be inherited into other frames if they're needed. Single or multiple values are added to a slot with *new-value* or *new-values*, which replace any previous values. Adding single or multiple values without destroying existing values is accomplished with *add-value* or *add-values*.

What do we have so far? We have defined a schema called *THING-TO-DO* and given it some slots and values. One of its slots is *FUN*, and we've given it a default value of *NOT-MUCH*. This schema doesn't have a lot of the slots a real *THING-TO-DO* would need (such as *DEPENDS-ON*, for example), but these can be added later as the need arises.

To see our *THING-TO-DO* schema printed on the terminal, another CRL function, *print-schema* is used. The schema is then displayed on the screen in print format. (LISP returns *T* for true after printing the schema):

```
> (PRINT-SCHEMA 'THING-TO-DO)
{{ THING-TO-DO
     PRIORITY: MODERATE
     RESOURCES: SYMBOLICS PRINTER
        CODING-PAD
     LOCATION: OFFICE
     DUE-DATE: 1-1-86
     FUN: NOT-MUCH}}
T
```

Just to be devious, let's try to add a value to a slot that does not exist (Listing 3).

Not a pretty sight! CRL comes back and tells us that it can't add a value to a slot if the slot doesn't exist. We could add the slot and then the value and everything would be fine. In CRL, the application developer can intercept these error reports and customize a message or recover from the error in any way he or she desires.

Let's create a schema called *PHONE-CALL* that can be used to represent the pertinent information in a telephone call. A LISP function called *CSCHEMA* (which is actually a macro) can be used to create a schema with its slots and values at one time rather than using the functions *CREATE-SCHEMA, CREATE-SLOT* and *NEW-VALUES*. *CSCHEMA* creates schemas such as *PHONE-CALL* with an arbitrary number of slots and values:

```
> (CSCHEMA 'PHONE-CALL
     ('IS-A 'THING-TO-DO)
     ('TOPIC)
     ('WITH-WHOM))
PHONE-CALL
```

To add a specific *PHONE-CALL* to the system, we again use the *CSCHEMA* macro. Since everything in CRL is a schema (Listing 4), a class such as *PHONE-CALL* and a specific instance of the class are both schemas. The slot *INSTANCE* tells the system that *PHONE-CALL-123* is a specific *PHONE-CALL*, which in turn is a *THING-TO-DO*. The relations between the schemas *THING-TO-DO, PHONE-CALL*, and *PHONE-CALL-123* are displayed in Figure 1.

If we want to find the value of a slot in a schema, the CRL functions *GET-VALUE* (to retrieve one value) or *GET-VALUES* (to retrieve more than one value) are used:

```
> (GET-VALUE 'PHONE-CALL 'IS-A)
THING-TO-DO
```

So we learn that a *PHONE-CALL* is a *THING-TO-DO*, which we knew already. Do we know anything about the location of *PHONE-CALL-123*, such as where I should make *PHONE-CALL-123* from?

```
> (GET-VALUE 'PHONE-CALL-123
    'LOCATION)
OFFICE
```

Although we hadn't explicitly entered a location to the *PHONE-CALL-123* schema, one can be assumed. The value of the location of *PHONE-CALL-123* is inherited from the schema *THING-TO-DO* via the *IS-A* relation. New relations can be added to the system readily, so any relation between schemas can be defined explicitly. CRL also provides features for including or excluding slots and values that can be inherited. *INCLUSION-SPEC* and *EXCLUSION-SPEC* schemas are used for this purpose.

Meta knowledge is knowledge about knowledge. Meta knowledge can be attached to a schema, slot, or value and used to record information about the knowledge base development, such as who added a particular schema and on what date. It can also be used to place restrictions on the values a slot can take and to set up demons or specify certain inheritance specifications.

Suppose I've already done my knowledge engineering task and I now know that valid PHONE-CALL topics must be related to a valid PROJECT, (another schema). I want the Things-to-Do Advisor to prevent somebody from coming in and saying that poetry is a valid phone call topic. This can be done by creating meta knowledge in the form of a restriction slot schema. A switch, which generally takes a *T* or *NIL* (true or false) value, must also be set to tell CRL to check restrictions:

```
> (CSCHEMA 'TOPIC
   ('RANGE '(SCHEMA (TYPE IS-A
      PROJECT))))
TOPIC
> (SET-SWITCH 'RESTRICT T)
T
```

Now if we try to set the value of the *TOPIC* slot of *PHONE-CALL-123* to *POETRY*, CRL will print an unpleasant "RANGE ERROR" message.

Once a domain of knowledge is properly represented in a network, the job of using the knowledge still remains.

```
> (CREATE-SLOT 'THING-DO-TO 'PRIORITY)
PRIORITY
> (CREATE-SLOT 'THING-DO-TO 'RESOURCES)
RESOURCES
> (CREATE-SLOT 'THING-DO-TO 'LOCATION)
LOCATION
> (CREATE-SLOT 'THING-DO-TO 'DUE-DATE)
DUE-DATE
> (CREATE-SLOT 'THING-DO-TO 'FUN)
FUN
```

Listing 1.

```
> (NEW-VALUE 'THING-TO-DO 'PRIORITY 'MODERATE)
MODERATE
> (NEW-VALUES 'THING-TO-DO 'RESOURCES '(LISP-MACHINE PRINTER CODING-PAD))
(LISP-MACHINE PRINTER CODING-PAD)
> (NEW-VALUE 'THING-TO-DO 'LOCATION 'OFFICE)
OFFICE
> (NEW-VALUE 'THING-TO-DO 'DUE-DATE '1-1-87)
1-1-87
> (NEW-VALUE 'THING-TO-DO 'FUN 'NOT-MUCH
NOT-MUCH
```

Listing 2.

We could use Common LISP exclusively. With this approach, the CRL schemas could be used as data structures only. The user could type in LISP expressions at the keyboard or write LISP programs that use CRL functions and schemas.

Another approach is to use demons. Here, schemas are attached to a slot, designated as demons and used to reference some code. When the slot is accessed (via *GET-VALUE*) the referenced code is called.

A third approach is to use object-oriented capabilities. In this scheme, functions are stored as values in slots. The functions are invoked when messages are sent to the schema containing the slot.

Inference capabilities are also provided with Knowledge Craft via PROLOG and OPS-5. These capabilities are not, however, part of CRL. In a real application, these control capabilities would be mixed and matched as appropriate.

CRL also offers a mechanism for portraying alternative worlds in its efforts to deal with hypothetical or conflicting information. Suppose in the Things-to-Do Advisor I want to differentiate between several schedules in which the tasks can be executed:

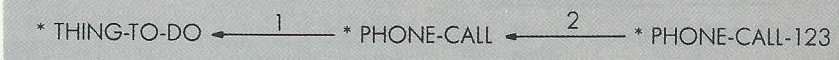
```
> (CSCHEMA 'TASK-1 :CONTEXT 'ALL-
    GOES-WELL
  ('DURATION .5)
  ('PERSONNEL 1))
```

```
> (NEW-VALUE 'THING-TO-DO 'PROJECT 'EXOTIC-LANGUAGE-COLUMN)

***     CRL ERROR REPORT
***     TYPE                NO SLOT
***     SOURCE              NEW-VALUE
***     IN SCHEMA           THING-TO-DO
***     IN SLOT             PROJECT
***     WITH VALUE          NIL
***     IN CONTEXT          $ROOT-CONTEXT
***     AUXILIARY MESSAGE   "Slot doesn't exist"
```

Listing 3.

Schema relations



Relation keys:
1. IS-A
2. INSTANCE

Figure 1.

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```
TASK-1
> (CSCHEMA 'TASK-1 :CONTEXT 'ALL-
      GOES-POORLY
   ('DURATION 50)
   ('PERSONNEL 10))
TASK-2
```

When one context has been chosen as the correct version of the world (hopefully the *ALL-GOES-WELL* context!), the contexts can be merged. This means the schemas in the *ALL-GOES-POORLY* (or *ALL-GOES-WELL*) contexts will be removed.

CRL can be fine-tuned by using a number of switches that control the tasks CRL is supposed to do. These switches allow the user to adjust the environment to better suit it to the problem. Most of the switches are Boolean (taking *T* or *NIL* as values), but there are a few with three- or more-way settings. Examples include *CACHE* (whether to copy inherited values into schemas), *DEMON* (whether checks are made for demons), *RESTRICT* (whether to check for range restrictions), and *INVERSE* (whether inverse relations are automatically created), among some 20 others.

A very good example which demon-

```
> (CSCHEMA 'PHONE-CALL-123
           ('INSTANCE 'PHONE-CALL)
           ('TOPIC 'MEETING-FOR-LUNCH)
           ('WITH-WHOM 'REED)
           ('PRIORITY 'HIGH))
PHONE-CALL-123
```

Listing 4.

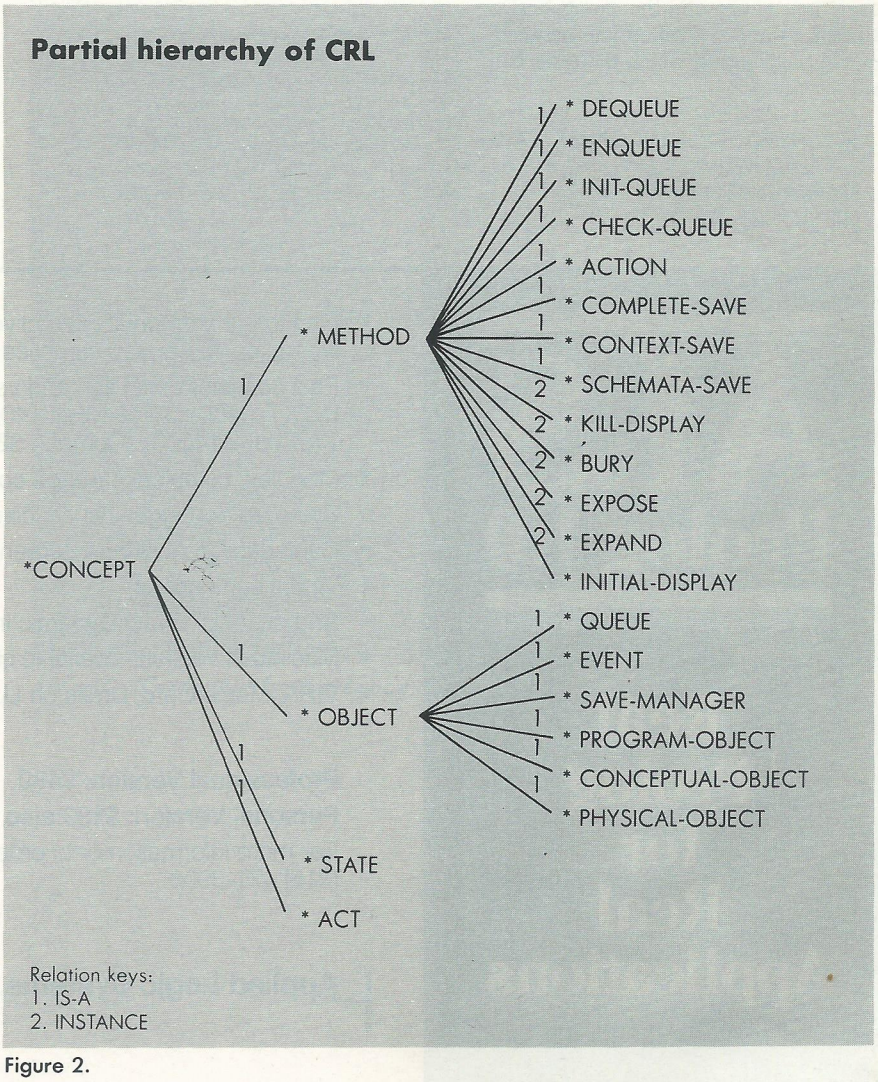

Figure 2.

strates the use of CRL to represent complex scenarios is found in a paper written by Arvind Sathi, Mark Fox, and Mark Greenberg,[7] in which schemas have been created for the important characteristics of project management, including abstraction, revisions, time, and constraints. The schema for *ELABORATION-OF* is shown in Listing 5.

This schema allows the *ELABORATION-OF* relation to be established between two schemas. This relation is similar to the concept of *ABSTRACTION,* where specific information is reduced along each link of this relation. *ELABORATION-OF* is a transitive relation, so if *A* is an *ELABORATION-OF B* and *B* is an *ELABORATION-OF C* then *A* is an *ELABORATION OF C.*

CRL understands the world through schema-colored spectacles. Everything of interest in CRL is a schema (frame). This includes relations, error recovery procedures, graphic objects, and utilities for manipulating CRL schemas.

In fact, the entire language can be represented in a hierarchy (partially pictured in Figure 2). This feature allows a CRL programmer to examine the CRL schemas (and possibly modify or extend them) as easily as the schemas that he or she has created. Listing 6 shows CRL schemas for *ERROR-SPEC, PROTOTYPE, EVENT,* and *DEMON.*

CRL offers many advantages to knowledge-based programming tasks. It provides an easy way to structure data so that it resembles the way we intuitively view it. Its uniform representation, in which everything is a schema that may contain slots and values, allows both computer manipulation and graphic representation.

Schemas can be used to capture both objects (such as *TASKS* and *PLANS*) and relations (such as *CONSTRAINED-BY* and *PROTOTYPE-OF*). In her book, *Artificial Intelligence,*[8] Elaine Rich states that to be useful, structured knowledge should possess four properties: representational adequacy, inferential adequacy, inferential efficiency, and acquisitional efficiency. In other words, the representation must be efficiently acquired, stored, and utilized.

CRL addresses these concerns to a large degree. The concepts behind CRL and the notion of knowledge representation can be useful for any programmer or analyst who must deal with the semantics of complicated knowledge.

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Doug Schuler is an AI specialist with the Advanced Technology Center of Boeing Computer Services. He is interested in knowledge representation and other issues underlying applications, such as computer-aided negotiation. He is currently coordinating the upcoming "Directions and Implications of Advanced Computing" Symposium sponsored by Professionals for Social Responsibility.


```
{{ ELABORATION-OF
    IS-A: RELATION
    DOMAIN: (OR (TYPE IS-A INDIVIDUAL)
                (TYPE IS-A PROTOTYPE))
    RANGE: (SCHEMA (OR (TYPE IS-A INDIVIDUAL)
                       (TYPE IS-A PROTOTYPE))
    INVERSE: HAS-ELABORATION
    INCLUSION: ELABORATION-OF-INCLUSION
    TRANSITIVITY: (REPEAT (STEP ELABORATION-OF T) Ø INF)
    COMMENT: "Elaboration-of defines abstraction"}}
```

Listing 5.

```
{{ ERROR-SPEC
   IS-A: PROGRAM-OBJECT
   TYPE:
   SIGNAL:
   ACTION:
   VALUE: }}

{{ PROTOTYPE
   IS-A: RELATION
   TRANSITIVITY: (STEP PROTOTYPE T)
   INVERSE: PROTOTYPE-OF }}

{{ EVENT
   IS-A: OBJECT
   QUEUE:
   EVENT-TIME:
   ACTION:
   NOTICE:
   DELETE:  }}

{{ DEMON
   IS-A: PROGRAM-OBJECT RELATION
   ACCESS:
   ACCESSOR
   ACCESS-VALUE:
   WHEN:
   ACTION:
   EFFECT:
   CURRENT-VALUE: }}
```

Listing 6.

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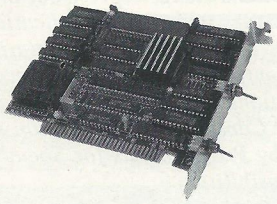

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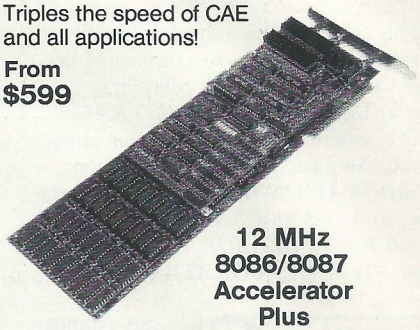

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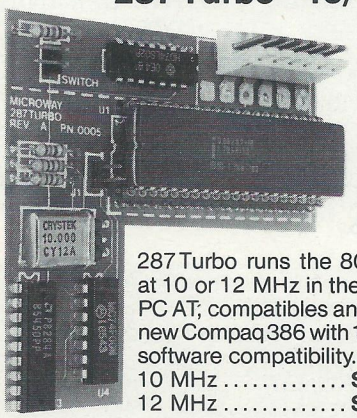

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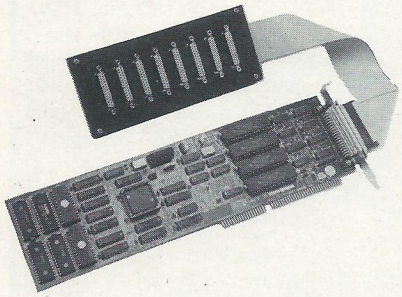

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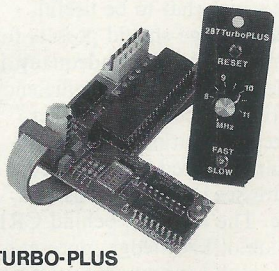

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PRODUCT BINGO

By Joanna M. Poole

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Death by 1,000 *cuts*: PROLOG on the PC

By Steven Engle, Jonathan Hodgson, and James Vita

As personal computers have grown more powerful, they've become host to increasingly complex programs. Fifth generation languages once used solely on mainframes are now delivered on much smaller machines.

One such language is PROLOG. Unlike more conventional, procedural languages, PROLOG incorporates program control into the language itself. The programmer is relieved of the majority of the control of program flow and can focus on expressing data objects' relationships. Ultimately, this design vests the language interpreter with responsibility for most of a program's functionality, making the implementation of PROLOG on a microcomputer a formidable task.

As with other functional languages such as LISP and Forth, PROLOG applications are created by incrementally specializing the interpreter environment until the desired functionality is achieved. This method inevitably leads to problems with standardization and portability.

There is currently no universal PROLOG standard analogous to common LISP or FIG Forth. Over time, the implementation described by W.F. Clocksin and C.S. Mellish in *Programming in PROLOG* (Springer-Verlag, 1985) has emerged as the de facto standard. Few implementers are satisfied with merely following the standard; most choose to embellish their PROLOG environments with a variety of powerful and innovative capabilities.

The proliferation of nonstandard features is encouraged by a professional programming community generally more concerned with the requirements of the task at hand than virtuous adherence to a standard. Many implementations have successfully merged these two goals by offering a complete Clocksin and Mellish implementation and various extensions—in some cases, even alternative control structures.

As the language moves to the personal computer, implementers must come to terms with the machine's requirements and limitations. A PROLOG interpreter is memory intensive; data and programs must be available in memory. Consequently, one of the most pressing limitations is memory size.

The packages reviewed handle memory limitations in a variety of ways, ranging from virtual memory systems to compression schemes—techniques rarely visible to the user. Interestingly, none of the PC-based PROLOGs reviewed here makes use of the extended or expanded memory capabilities of the 80286 or 80386 processor, using instead methods that are compatible with standard PCs.

The packages also take several approaches to the delivery of applications. The most efficient approach is, of course, to compile interpreted code into a standalone, executable image. A disadvantage of this approach is the frequent need to introduce subtle changes into the interpreted code to facilitate compilation (such as typing of expressions and the declaration of predicates before they are used).

Other systems offer run-time environments that create essentially self-starting applications but otherwise continue to interpret code. A variation of this approach is systems that compile code into compact intermediate representations that execute faster and load more quickly.

In a similar vein, the integration of PROLOG applications with code in more conventional languages, such as C or Pascal, is interesting. Particularly intriguing are applications that make use of an existing data base product to extend the local PROLOG data base. The way this is done is by no means standardized; each product handles the interface differently.

Judging by the variety of products, the audience for PROLOG interpreters differs greatly from the users of more conventional languages. In many ways, the PROLOG market is still in its infancy, resulting in products that range from those produced by small groups of programmers in close contact with their user community to more polished efforts by larger organizations.

This diversity is healthy, and there's quality to be found over the entire spectrum of products. A PROLOG whose manual comes in a loose-leaf notebook is not necessarily inferior to one whose manuals are bound. The range of products available is indicative of the variety of PROLOG applications, spanning the complete range from academic research to professional product development.

The following products are covered: Applied Logic Systems' ALS PROLOG, Arity's Arity/PROLOG, Chalcecony Software's Chalcedony PROLOG/i, Cogent Software's Cogent PROLOG, Logicware's MPROLOG, Expert Systems International's PROLOG-2 Professional, Borland International's Turbo PROLOG, and Automata Design Associates' VML PROLOG. Tables 1 and 2 (pp. 132 and 134) summarize the benchmark results and features.

In general, the products reviewed were of consistently high quality. What separates them is the underlying engineering and the specific mixture of features that determine how well an interpreter will fit the application at hand.—S.E.

Applied Logic Systems
ALS PROLOG

Applied Logic Systems' ALS PROLOG comes on two disks: one for the system and the other with example programs, C interface files, and source code for many of the built-in predicates. Installation is completely straightforward and clearly explained at the beginning of the users manual.

ALS PROLOG permits access to DOS and an editor from within the program development environment. The package comes with two versions of Manx Software's Z text editor. One version is for true PC compatibles and directly manipulates the screen; the other uses DOS to address the screen. Z is a version of the Berkeley UNIX vi editor. If you don't want to use vi, it can be easily replaced with one you prefer. You can even change editors during an ALS PROLOG session.

ALS PROLOG is fairly close to the Edinburgh PROLOG of Clocksin and Mellish. The additional predicates Applied Logic Systems has included fall into three groups: the usual PROLOG extensions (*bagof, sort,* and so on), special PC extensions (DOS commands, a

command to invoke the editor, and BIOS services), and a special group of predicates related to implementation details of ALS PROLOG.

These last predicates are worth mentioning; they may help explain how ALS PROLOG achieves its amazing speed. ALS PROLOG is implemented using a threaded code interpreter for an abstract PROLOG machine. A manual section gives some details on how you can access the machine's code generator through the built-in predicate *$icode*.

Interestingly, even predicates that undergo assertion or retraction are compiled by the compiler. In addition, the compiler does complete garbage collection on both *heap* and *trail*. The compiler implements last-call optimization—predicates that use tail recursion are optimized as a special case.

Using the system is quite straightforward. To consult files, put their names on the command line when you invoke the compiler; they're automatically reconsulted when you return from the editor. It's worth noting that if a file name includes the .PRO extension when it appears on the command line, the compiled file won't be written to disk. If the file doesn't include the .PRO extension, the name will be given a .OBP extension and the compiled file written to disk. As a result, files invoked with the .PRO extension run slightly slower than those in which the compiled version was written back to disk.

ALS PROLOG does not produce stand-alone code. However, if you put a suitable goal in the files that are consulted on the command line, you can produce a program that can be run in a batch file. (Returning to DOS requires the use of the undocumented predicate *halt*.)

The example programs on the second disk cover a wide variety of problems and are well worth studying. In some cases, the source code has better documentation than the manual. There needs to be a more complete explanation of invoking programs. One particularly impressive example is a programmable desk calculator that makes use of definite clause grammars, useful for writing parsers. (See the accompanying sidebar "PROLOG benchmarks," pp. 130-131.)

While most of the error messages were helpful, some were less so. For example, if you're on the command line and try to consult a file that's not on the drive specified, the error message will be "error loading file <filename>." Unfortunately, this message covers many possible errors, including the destruction of a file. While this is an extreme example and most of the other error messages are better, I don't think that just because a compiler is directed to professionals you should skimp on things like error messages.

The manual is on the terse side and definitely written for experts. To be fair, it does come with an order form for Ivan Bratko's *PROLOG Programming for Artificial Intelligence* (Addison-Wesley, 1986).

I have a couple of minor complaints. Since some of them are about things that can affect your programming, I'll list them.

ALS PROLOG does not mind if the right-hand side of the predicate *X is Y* is uninstantiated, preferring to fail the goal at this point. This certainly does not accord with Clocksin and Mellish, although it could be used to initiate backtracking in some situations.

ALS PROLOG normally only produces the first instantiation of the variables in a goal. After writing them to the screen, it stops on the same line as the output. Nowhere in the manual does it tell the user that a semicolon will cause ALS PROLOG to try and redo the goal. I mention this because although this feature is fairly standard in PROLOG implementations, it is by no means universal.

On a more positive note, ALS PROLOG provides support for creating large programs through the use of modules. They're similar to the modules in Modula-2 in that predicates must be explicitly exported from a module if they are to be used elsewhere. Since you can't ac-

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cess predicates that haven't been exported from a module, information hiding is possible. However, information hiding can't be completely realized since you can still explicitly assert into or retract from a module.

When a module is loaded, invocation of the predicate listing will display all its predicates on screen, including those that are not exported. In spite of these quirks, ALS PROLOG's support of modules is indispensable for large programs.

The usual debugging facilities provide for tracing a goal. In addition, spy points can be set and leashing is permitted. PROLOG debuggers inevitably produce large amounts of output, and this one is no exception. If you do invoke any of the debugging predicates, the debugger .OBP file is consulted. Otherwise it is not normally loaded, saving room in the symbol table.

How well does ALS PROLOG perform as a compiled version of PROLOG? I've mentioned that it is amazingly fast. On a Zenith AT-compatible that's about twice as fast as IBM's PC/AT, programs ran at a consistent 18,000 logical instructions per second (LIPS). On an Eagle PC-compatible, performance was 3,000 LIPS.

While the benchmark suite required minimal adaptation, some of them could not be modified without losing much of their significance. ALS PROLOG's compiler restricts the number of arguments to a predicate to 15 or less in accordance with the 16-register architecture of the compiler's abstract target machine. One consequence of this is that the call *functor(T,f,16)* will fail.

I ran most of the examples that came with the system and found that they all worked as advertised. As mentioned, the examples are of high quality and reward careful study.

Since I didn't have any large programs available, I couldn't test the compiler's support for procedure swapping. This facility keeps track of the least frequently used procedures and swaps them out of memory when more space is needed.

Any programming environment should provide some hooks into the operating system. ALS PROLOG offers two methods: built-in predicates to do the work of C library functions of the same name (essentially, it forks a process), and other predicates to address video and keyboard BIOS routines. These are supported by SCREENS.PRO, a module that provides various graphics primitives. If you have Manx's Aztec C compiler, you can also call C programs from ALS PROLOG, but this is the only compiler presently supported. It seems a pity that the DOS function calls are not directly supported.

For a software development environment, ALS PROLOG's restriction that file handling be done only through *see* and *tell* is a severe limitation that makes accessing data base files difficult. However, Applied Logic Systems has announced a separate package that will interface ALS PROLOG to several of the standard data base packages, which should considerably enhance the value of ALS PROLOG for applications development.

I found ALS PROLOG a very comfortable environment to work in. I appreciate the close adherence to the Edinburgh standard and the truly amazing speed of execution. ALS PROLOG is a complete package suitable for many AI applications, particularly systems run from some top-level interface or those that will add their own rules. The limitation on the number of arguments to predicates could hinder data base applications since it will restrict the number of attributes a relation can have.

Although ALS PROLOG does not offer the kind of bells and whistles a windowed environment with pop-up menus does, it does present a smooth interleaving of editing and testing, very much in the spirit of UNIX. Programmers who like the UNIX environment will probably like this compiler. In spite of some reservations about the documentation, I really liked the product. Anyone interested in writing large programs in PROLOG should check it out.—J.H.

Arity Corp.
Arity/PROLOG
Arity Corp.'s Arity/PROLOG is an implementation of the Clocksin and Mellish

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standard for professional software development. The system I reviewed included an interpreter, compiler, and sets of development utilities and example programs. The package provides extensive support for a wide set of commonly used PROLOG extensions, including second-order predicates, alternative control structures, and data base control predicates. Also included is support for definite clause grammars and extensive access to PC BIOS functions.

Arity/PROLOG has an introductory manual, installation guide, reference manual, and compiler guide and is delivered on four noncopy-protected disks. To install the program, simply copy the floppies to the hard disk and define two DOS logical names to identify the editor and the path to the nonexecutable system files. Instructions are included for installation to floppy-based systems, though the usefulness of such a system is questionable. The package does not include an editor, though most any file editor capable of working with straight ASCII files is accessible without leaving the interpreter.

While the documentation is thorough and well executed, it is directed at the professional user and does not introduce PROLOG to beginners. The installation guide provides a quick set of examples on how to work with the interpreter, clearly explaining starting the interpreter, exiting to DOS, and other tasks that do not fit well into the language manual.

The language manual is complete, easily navigated, and includes an index (eliminating linear searches of the manual). Each predicate is presented with examples; the more involved sections include several introductory pages. The absence of the obligatory 10-page introduction to PROLOG signals the package's intended audience.

The third manual details the operation of the compiler and procedures for building stand-alone, compiled applications. These applications do not require an interpreter, making Arity/PROLOG a candidate for developing marketable products. This manual is detailed, well structured, and, again, clearly intended for the experienced user.

Arity fully implements the Clocksin and Mellish standard, including definite clause grammars and second-order predicates like *bagof, findall,* and *setof.* Despite adherence to the standard, usability has not been sacrificed. The standard functionality is extended in a variety of ways, resulting in a complete system that is more usable.

Arity includes a special *counter* data type and a number of operators for bitwise operations and ordering and sorting atoms. In many cases, both integer and floating-point versions of the generic arithmetic operators are provided for use when efficiency is a concern.

Arity departs from the Clocksin and Mellish standard with its handling of the string data type. Rather than store strings as lists of atoms or lists of characters—both awkward for programmers and users—Arity stores strings as arrays of integer values delimited by the dollar sign. This approach conserves memory space while still allowing keyword searches, natural user input, and string manipulation. Built-in predicates support manipulation and conversion of strings to various other data types.

Arity provides two interesting, nonstandard control structures: *case* and *snip.* The *case* operator alters the goal according to the value of an expression. Its syntax is illustrated in the example from the Arity manual shown in Listing 1. Note the vertical line between the final two terms that delimits the default case.

The *snip* operator extends PROLOG's venerable *cut* operator (*!*), providing more control over backtracking. *Snip* is essentially a *cut* whose scope can be limited to a set of contiguous terms. In the following case, the failure of the predicate *E* would result in a failure of the entire expression: *A :- B, C, D, !, E.*

In contrast, if you use *snip* in the following expression, the failure of *E* causes backtracking to proceed from the *B* term: *A :- B, [!C, D!], E. Snip* is used to limit the search space but not as drastically as a *cut* would.

Arity extends the PROLOG's data base capabilities with three methods for organizing data bases: worlds, B-trees, and hash tables.

Worlds partition a data base, thus reducing the size of a search space. Worlds can be categorized as code worlds, which contain clauses and predicates, and data worlds, which are limited to data. However, unless otherwise specified, all actions occur in the default world, thus maintaining compatibility with applications that don't make use of this feature. Worlds can also be saved to files, allowing limited overlaying and freeing data-intensive applications from the memory constraints of a PC host.

Balanced binary trees (B-trees) and hash tables are accessible through a series of predicates similar to the standard data base access predicates. The predicates accept a tree or hash table name, a key, and the term to be stored in the structure. Because Arity provides access to the absolute data base location of any given predicate, it is also possible to store indexes in B-trees or hash tables, allowing you to index the data base under multiple keys.

The package provides the full complement of I/O predicates as defined by Clocksin and Mellish. Several additions are made to support IBM PC-specific functions, such as retrieving keyboard scan codes, accessing directories, and forcing duplicate file handles. Random access to files is supported with a predicate for specifying an offset address relative to the beginning of a file. Low-level access to PC ports is also provided.

Arity allows access to DOS functions through a variety of built-in predicates, including text-screen management with scrolling subregions of the screen, file management, and date functions. Windows are not directly supported, though implementing them should be within most users' grasp.

One glaring omission is the lack of access to the interrupt instruction. Since this could be added to the interpreter in a variety of ways, it's odd that it's not included, forcing programmers to devise their own means of accessing functions that are not built-in.

True to its stance as a serious development system, Arity/PROLOG includes a complete set of debugging tools. Full support is provided for the procedure-box model, allowing traces to be associated with all four ports of the standard execution model. The volume of trace information can be controlled using the leash predicate, reducing superfluous trace information.

Arity/PROLOG is not intended for the casual user. The manual details how to interface the language with a wide variety of languages. The package provides extensive compilation control, including generating *FAR* calls, declaring data types for code optimization, and limiting the accessibility of particular predicates. The package includes a family of predi-

```
case([ X = 0 -> write($The day is Sunday$),
       X = 1 -> write($The day is Monday$),
       X = 2 -> write($The day is Tuesday$),
       X = 3 -> write($The day is Wednesday$),
       X = 4 -> write($The day is Thursday$),
       X = 5 -> write($The day is Friday$),
       X = 6 -> write($The day is Saturday$) |
                write($Invalid date$)])
```

Listing 1.

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■ Clean, Complete Documentation

C-scape's documentation is a clear example of how to write for programmers in a hurry. A short introduction uses helpful examples to explain the C-scape design. Each function is documented separately. An index makes reference easy, and a quick-reference card provides a synopsis of each function.

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cates for interfacing to assembler, Microsoft and Lattice C, and Microsoft FORTRAN and Pascal modules. The compiler package also includes a lint facility for locating potential trouble spots prior to compilation.

Assembly language routines can be added to the interpreter environment's built-in predicates with a declaration compiler. To do this, compiled predicates are added to the code world of the interpreter, and matching PROLOG predicates are declared to access the new predicate.

Arity/PROLOG offers a powerful and well-appointed development environment. It's a professional-class system suitable for both product development and research. The system is well documented and supported. The package has the style of a faithful implementation of Clocksin and Mellish PROLOG while meeting the needs of the software professional. —S.E.

Chalcedony Software
Chalcedony PROLOG/i

Chalcedony (pronounced "kal-SED-ony") Software's PROLOG/i is a significant advance over its earlier PROLOG/V. While still an interpreter, PROLOG/i supports large-memory-model applications (up to 640K RAM), math coprocessors, user-written overlays, and operating system commands, as well as a rich screen- and file-handling vocabulary.

Chalcedony's PROLOG/V and PROLOG/V Plus have been on the market since about 1982. As their successor, PROLOG/i retains compatibility with those products, as well as adhering to the Clocksin and Mellish standard.

PROLOG/i's user interface resembles a PROLOG user dialogue, similar to that described in Clocksin and Mellish. However, the dialogue differs somewhat from most other implementations' and the Clocksin and Mellish standard. If you enter a clause followed by a period at the user prompt (>), the clause is assumed to be a term and automatically asserted into the data base. To query the data base, a term must be followed by a question mark.

I can't fault the choice of a period for an assertion and a question mark for a query, as these are certainly logical assignments. However, this deviation is somewhat distracting to the flow of the PROLOG dialogue. I often want to consult files and query facts in these files. On most keyboards, the PROLOG/i syntax requires an extra, shifted key press. The deviation is less convenient than the more familiar syntax in which a period represents a query. However, this quirk is easily learned and becomes less distracting with practice.

PROLOG/i comes with its own editor so you can immediately begin building real PROLOG files. The editor somewhat resembles WordStar, but the command sequences are totally different. Many users will not be interested in learning the syntax of yet another editor. For them, detailed instructions are given for installing their own word processor or text editor that can be called from the PROLOG/i environment.

One major addition to the standard Clocksin and Mellish predicates is the ability to save the current data base. The *save* predicate dumps the current data base (minus comments) into a file, a feature particularly useful for experimentation.

The ordinary predicates *consult* and *reconsult* can also be used to read a data base back into the PROLOG/i work area. However, the additional predicates *load, reload,* and *unload* can be used to achieve effects not attainable with standard PROLOG. When *load* reads clauses from a file, PROLOG/i keeps track of the files they came from. The predicate *reload* acts like *reconsult,* affecting only the clauses associated with a particular file.

The built-in predicate *unload* selectively removes any clauses that were loaded from a specified file (acting like an all-encompassing, though selective, *retract*). Taken together, these features give the programmer total control over the data base and can be invaluable during a debugging session. PROLOG/i does not support the *[user]* syntax for adding terms to the data base from the keyboard. Instead, the user can consult the special file *con:*.

PROLOG/i provides a rich superset of the features of standard PROLOG. The *op* predicate is supported, allowing the user to define new operators. PROLOG/i handles PROLOG terms as data objects using the familiar *functor, clause, term, arity,* and *arg*. PROLOG/i does not support the dot (.) as either an infix or prefix operator on a list. The *op* predicate cannot be used to define such an operator. Nevertheless, a powerful set of list-handling features are provided. Multiple declarations are supported (predicates with the same functor name but differing in arity).

The standard arithmetic and comparison operators are included with only minor variations (for example, a normal slash instead of a backslash for /==). PROLOG/i handles floating-point numbers, as well as signed integers in arithmetic expressions.

Special formatting predicates allow the precision of results to be controlled. For example, floating-point output can be specified to be in scientific notation or fixed-point notation with a specified number of significant digits before and after the decimal point. In addition to the standard arithmetic predicates, PROLOG/i provides a full range of extended functions including double-precision arithmetic, exponentiation, and trigonometric and transcendental functions.

File I/O is handled with the standard *see, seeing, seen, tell, telling,* and *told* predicates. In addition, PC/MS-DOS users can manipulate directories and default drives with *chdir* and *chdisk*. Output can be directed to the screen or printer. For owners of computers that aren't completely IBM-compatible, ANSI screen I/O is possible once the ANSI.SYS device driver (not provided) is properly installed.

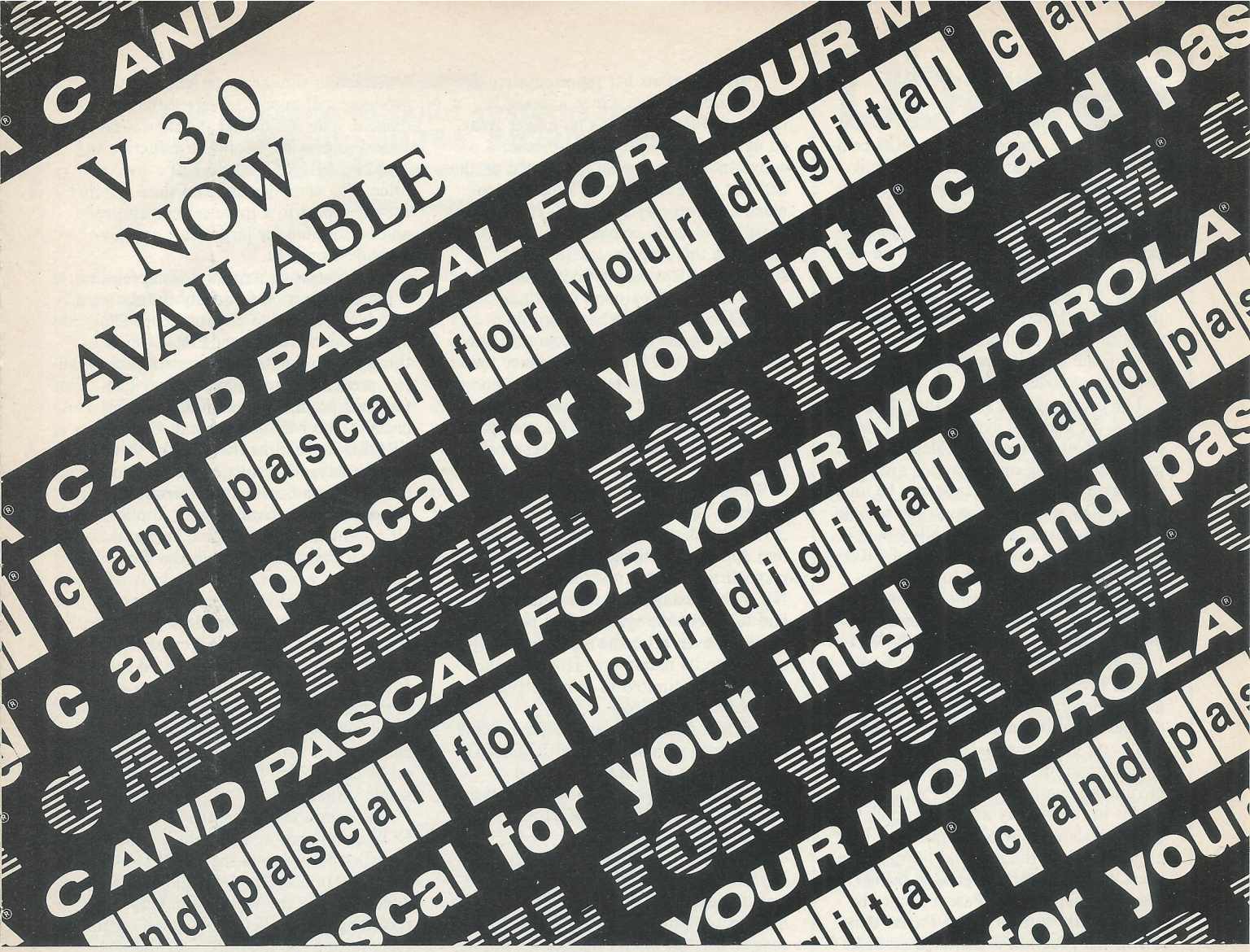
Users with color graphics (CGA) systems can take advantage of some machine-dependent graphics features. Predicates are provided to set the display mode of the computer and to read and set individual pixels on the display with up to two color palettes. PROLOG/i supports all of the standard IBM display modes, including high resolution (640 x 200 pixels).

With these features, you can make some interesting forays into the world of pattern generation and recognition. Limited text-oriented graphics are also supported. In that mode, you can do such things as clear the screen, plot the cursor, and control the scrolling of windowed screen areas.

PROLOG/i's debugging facilities are essentially identical to those described in *Programming in PROLOG*. You can leash the various PROLOG ports (*CALL, EXIT, FAIL,* and *REDO*) for a step-by-step trace of a program's execution. To debug new code, individual predicates can be designated as spy points; tracing can be turned on or off at any time. Debugging is performed in the main window as part of the normal PROLOG/i dialogue.

The PROLOG/i package has two manuals. The first manual, essential to the new user, is a language reference and tutorial. Its 184 pages include a brief introduction to PROLOG techniques, an indexed listing of built-in predicates, a listing of PROLOG dialogue error messages, and a glossary. This manual is not intended to be a complete course on PROLOG; for further information, the user is referred to *Programming in PROLOG*. The second manual is a users guide, a detailed, 76-page treatise on the editor and advanced topics.

PROLOG/i can be extended by manipulating the overlay library where many of the built-in predicates reside. Most of the PROLOG predicates are part of the system kernel. However, PROLOG/i maintains a transient overlay area that it uses to run DOS commands and call



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predicates that reside in external libraries.

Several sample programs demonstrate how compiled, Pascal, C, and DOS command programs can be executed from within a PROLOG dialogue or program using the *loadexec* predicate. In addition, several examples illustrate how the external PROLOG/i library can be extended by including compiled C programs. (The technique involves relinking the existing library with the compiled versions of the predicates.) To use this system, the compiler must produce standard object-code output.

The users manual states that the format of the external overlay area is proprietary. Consequently, the details of performing these modifications are somewhat sketchy, although they can be understood by working through the sample source programs. This capability is not essential to the basic operation of PROLOG/i and is better left to the experienced DOS programmer.

PROLOG/i comes on two noncopy-protected disks. The first has the PROLOG/i interpreter, library, and library linker; the second, a few sample programs. Several of the sample programs are described in the language reference and users guide manuals.

The program disk includes examples of running compiled C and Pascal programs in the overlay area. A sample C program shows how to compile and link a program into the external library. The users guide makes reference to using these techniques with Pascal programs but explicitly states that no Pascal demonstration program is included on disk.

The sparsity of sample programs is the only shortcoming of PROLOG/i's reference materials. Overall, the documentation is accurate and well written.

Technical support is not included in the purchase price. Instead, the user is encouraged to join a users group at a modest cost. Joining the group entitles you to a quarterly newsletter and access to a resident programmer. Owners of PROLOG V and PROLOG V Plus can upgrade to PROLOG/i for $20. Version updates are available to registered users for the cost of shipping and handling.

PROLOG/i generally performs as expected. One inconsistency is its treatment of strings. Standard syntax treats a string as a list of ASCII characters (literally, a list of numbers that represent the ASCII characters). PROLOG/i treats strings as a list of characters represented as atoms (the characters themselves). Several predicates (notably, those that allow external program calls) require strings as arguments.

A string and its list representation are not interchangeable. Once a string is read into PROLOG, it's no longer treated as a string. A predicate to build a command string can be performed on the list, but these lists are no longer recognized as strings by PROLOG/i. The list must be formally converted back into a string. In this respect, treatment of strings has a strongly typed nature. Apart from its treatment of strings, PROLOG/i is otherwise untyped.

Assessing the speed of programs run under PROLOG/i is difficult since the overlay library only provides the crudest of mechanisms for timing execution speeds. However, PROLOG source programs load and execute with reasonable speed.

When reading one of the benchmark files that had approximately 150 tail-recursive predicates, the PROLOG/i system appeared to hang and did not respond to a keyboard-executed break. No error message was reported, and I had to reboot the system. The problem persisted even after the stack size was increased to its maximum. However, the problem was limited to this one type of PROLOG source file.

I should note that this excessive use of tail recursion is neither good PROLOG programming practice nor typical of most PROLOG programs. With well-designed programs, PROLOG/i performed admirably.

For both novice and veteran, Chalcedony Software's PROLOG/i will be a rewarding experience. PROLOG/i is very much a programmer's PROLOG. It's easy to use but allows further growth as experience is gained and expertise developed. Its expandability, graphics, and high-level arithmetic support make it a worthy candidate for large-scale AI systems development.—J.V.

Cogent Software
Cogent PROLOG

Most microcomputer language products strive to achieve a certain syntactic richness while maintaining compatibility with a de facto standard. Living up to its name, Cogent PROLOG quietly accomplishes both goals.

The veteran PROLOG programmer with knowledge of the standard PROLOG syntax will find Cogent an easy way to transfer that experience to the micro. In its literature, Cogent Software describes its PROLOGs as being very close to the Clocksin and Mellish standard. With only a few exceptions, Cogent PROLOG lives up to this claim.

The Cogent PROLOG interpreter appeared about one year ago and is currently in its third version. As of my writing this review, the compiler and runtime system were scheduled for release in early May 1987.

Although similar in design, the two products will appeal to very different audiences. The interpreter package is designed to provide a solid introduction to standard PROLOG syntax at a modest price. The compiler and run-time system should appeal to a more serious audience and be suitable for large-scale applications development.

The interpreter's most striking feature is the emphasis on faithfully simulating a standard PROLOG environment. Communication with Cogent PROLOG is through a dialogue that consists of control predicates, goals, and terms. The top-level prompt (or main listener) expects the user to enter a goal. Cogent PROLOG attempts the proof of this goal and displays its results in the form of a dialogue on a continuously scrolling screen. A term containing an implication (*if* or :-) is assumed to be a rule and is automatically asserted into the data base.

Cogent PROLOG has several modes for adding clauses to the data base. The standard input file, *[user]*, creates a context for a series of terms to be added from the keyboard. Of course, the standard predicates *consult* and *reconsult* are available for adding clauses dynamically from a list. You can also consult a series of program files or libraries in a single statement.

The *comm* predicate allows access to DOS commands and permits an editor to be called from inside the PROLOG environment. Interactive debugging can be done by using the editor to modify a file, returning to the PROLOG environment, reconsulting the modified file, and testing the result with a new goal.

The Cogent PROLOG system kernel has all of the standard predicates. *Assert, assertz, clause, arg, retract, retractall,* and *op,* to name a few, are all made available by specifying that the standard PROLOG library be automatically consulted when the PROLOG environment is entered. In addition, you can create and specify private libraries that will also be automatically consulted at start-up.

Cogent's implementation has no constraining data typing and also allows two or more predicates differing in arity to have the same name. These are all standard and essential features for the experienced PROLOG user.

Cogent PROLOG has the same debugging facility as is offered by traditional Clocksin and Mellish implementations. You can set spy points and trace the execution of each predicate as its proof is attempted. A leashing facility single-steps a program's execution. Cogent PROLOG has a "careful" mode that allows you to catch many errors of-

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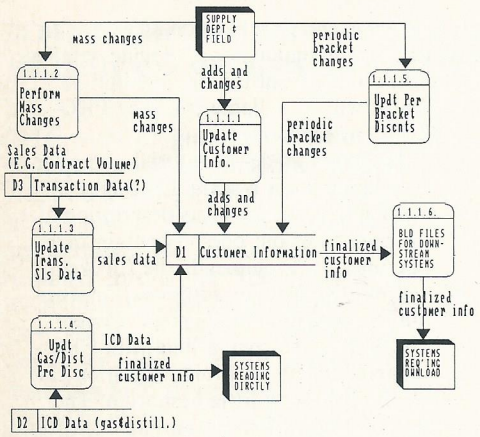

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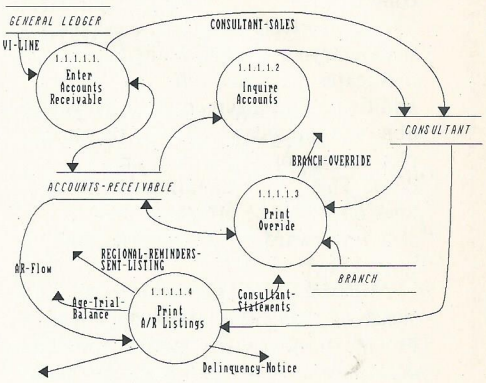

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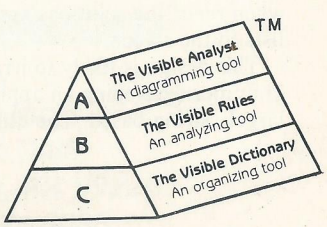

CIRCLE 61 ON READER SERVICE CARD

ten associated with misspellings of predicate names.

A microcomputer language implementation wouldn't be complete if it didn't take advantage of machine-specific features. Cogent PROLOG has a number of built-in predicates that allow operations like writing to the screen, calling MS-DOS BIOS interrupts, reading the system clock, and executing DOS commands.

Cogent PROLOG's rich file-handling vocabulary supports the standard syntax predicates *see, seen, tell,* and *told.* In addition, modest screen handling is available with predicates to clear the screen, plot the cursor, and create simple windows. This screen-handling facility allows results to be presented in a straightforward but graphically interesting manner.

Although the Cogent interpreter is basically just that (an interpreter), it does provide an alternative method for storing data base files, which it calls fast load format. This is a proprietary file format that allows program files to be consulted at twice the speed of the standard ASCII format. However, the use of fast load files has absolutely no effect on the execution speed of applications.

Compatibility with the Clocksin and Mellish standard is critical to the usefulness of a language implementation. Cogent PROLOG is a faithful representation of the core syntax, with only a few major variations.

First, only one definition of an operator may be in force at any one time. This disallows the use of the minus sign as both a unary and binary operator in a single expression, for example.

Second, if a variable is instantiated to a term, then that variable may not be used as a goal in the body of a clause. The Cogent syntax requires that the predicate *Call(Term)* be used instead to evaluate the term.

Finally, the dot operator, a convenient functor for the manipulation of lists, is conspicuously absent.

Overall, Cogent PROLOG seems to be a well-designed package with a modest superset of Clocksin and Mellish PROLOG features. Compatibility with the standard syntax was a major consideration in Cogent's design.

The resulting product is somewhat lacking in the details that give a program aesthetic appeal. For example, strings are internally represented as lists of ASCII codes. Cogent PROLOG uses this format when reporting solutions and displaying lists to the screen.

This design is likely to irritate the programmer developing an application that's largely string-based. The difficulty can be overcome by avoiding string representations (expressions enclosed in double quotes) and developing applications that manipulate atomic representations (expressions enclosed in single quotes) instead. The library predicate *name* converts data from one representation to the other.

Functor names are essentially limited to eight characters since only those characters are considered when the interpreter parses an expression. This limitation could produce unexpected results if you're not careful with predicate names.

There's no access to a DOS window, although specific DOS commands can be executed at the top level or from within a program. The manual states that only external DOS commands (those with an extension of .COM and .EXE) can be executed. Actually, the procedure works with any DOS command-type file, including *DIR, COPY,* and *RENAME,* as well as batch files.

The current version of the interpreter does not handle floating-point numbers; arithmetic is limited to 16-bit signed integers.

The only facet of Cogent PROLOG's design that I question is the absence of automatic garbage collection. PROLOG is extremely memory-intensive. Whenever a procedure call is made, PROLOG must save information about the current environment, backtracking points, and variable bindings. Memory to save this information is obtained from several pools of storage known as the heap, local stack, control stack, and trail. When a clause is retracted, some memory can be reclaimed because this implies that the clause will no longer be needed in a proof.

The Cogent interpreter does not automatically reclaim memory that has been dynamically freed. Instead, it marks clauses that are no longer needed and hence are potentially reclaimable by stacks or the heap. Heap management is augmented by two predicates: *stats,* which returns the number of reclaimable heap cells, and *gc,* which performs actual garbage collection at a user's request.

This garbage collection can be performed during the execution of a program or at the top-level prompt. A large application that dynamically adds and retracts clauses from the data base with great frequency can experience memory allocation problems.

To circumvent this problem, a large program must contain additional code to properly monitor and manage the heap. Similarly, stack-intensive programs may run into difficulty, especially when tail-recursive procedures are used to excess. No checking is performed to eliminate tail recursion.

Although stack and trail sizes can be preset to their maximums, memory must still be available for the program, library, and text editor. For serious applications, a fully populated memory board is essential; the suggested minimum of 256K RAM will allow only the most rudimentary of programs. Despite these limitations, stack and heap overflows are handled in a civilized manner by informing the user of the need for garbage collection.

The Cogent package doesn't have an editor. The manual does provide detailed instructions on installing an editor so that it will be callable from the PROLOG environment.

The users guide—a tutorial and reference manual—is a scant 109 pages. The manual is adequate in its description of the predicates but doesn't contain many examples; it recommends the Clocksin and Mellish text for additional information on program development. Cogent PROLOG is so compatibile with Clocksin and Mellish that this suggestion can be accepted with little hesitation. The manual's lack of programming examples is ameliorated by the release disk, which contains approximately 50 sample programs. Technical support is available by telephone or mail directly from Cogent.

The Cogent interpreter is very much a product for the Clocksin and Mellish purist. For the experienced PROLOG programmer who regularly uses a standard standard implementation and isn't necessarily interested in flashy graphics or windows, Cogent PROLOG will be a satisfying experience.

The interpreter is an excellent educational tool in a setting where mainframe or minicomputer access is limited but the desire to teach or use the Clocksin and Mellish syntax is keen. Despite its limitations, Cogent PROLOG amply demonstrates that it is possible to adhere closely to a standard—and even go a little beyond.—J.V.

Logicware MPROLOG

MPROLOG's manual explains that MPROLOG is an abbreviation for Modular PROgramming in LOGic. Logicware's designers take modularity very seriously; the user must do likewise.

MPROLOG is designed to be operating-system independent, insofar as such a thing is possible. The user interface is to look the same whether you're using a PC or a CDC Cyber. Logicware states that MPROLOG runs on the Atari 1040ST, CDC Cyber, DEC VAXes, HP 3000, IBM mainframes, ISI, M68000 workstations (Apollo, Sun, and such), and Pyramid systems. While this does not mean you can't use features peculiar to a particular machine's operating system, it does mean that the integration of such features into an application is not as

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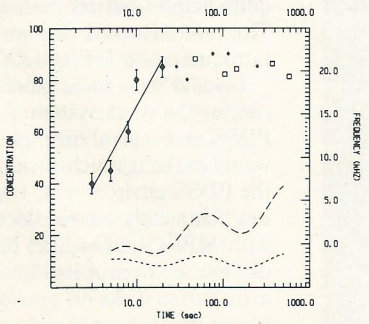

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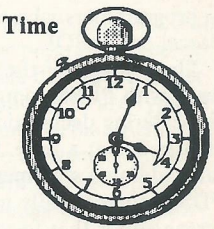

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seamless as it might be in an implementation for a single machine.

The heart of the MPROLOG software development package is Logic-Lab, or program design support system (PDSS). As indicated, Logic-Lab is intended to support modular programming. An MPROLOG module is a collection of related predicates, some (or all) of which are visible from outside the module.

An MPROLOG program is made up of one or more modules, of which the main module has a goal. Modules can be activated or deactivated during the running of a program, allowing the user to create very large programs if desired. The separate modules can be linked together into a single program that can run separately using the interpreter.

The creation of a large MPROLOG program proceeds by first designing the program's module structure. (Top-down design is taken quite seriously.) This is best done on paper since it's essential to have a chart of a module's structure for working on it with PDSS.

A typical (small) module is shown in Listing 2. I took this module from the distribution disks; it's part of the suite of modules used for checking correct installation. (Incidentally, the installation section of the manual is exceptionally clear and easy to follow.)

The module's division into a declaration section and a body is based on Logicware's professed desire to make MPROLOG more friendly, particularly to programmers whose background is in Pascal or COBOL.

The contents of the module are entered with PDSS commands, which permit entering declarations or single clauses one at a time. If you make a mistake adding a statement to a module, PDSS automatically invokes a built-in screen editor that focuses on the single item being entered, an extremely useful feature during program construction. To change the predicate *test* in Listing 2, you can just type *edit test* at the PDSS prompt.

You can type in goals at the command-level PDSS prompt to test the module as you work on it. If an error occurs during an attempt to fulfill a goal, the trace mechanism is automatically invoked—another useful feature. Once you get the hang of working in PDSS (which requires a moderate investment of time), it's a very good environment. Since most of the the programs I wanted to run required minor adjustments to be compatible with MPROLOG, I was grateful for the system's capabilities.

Once you've debugged a module, a pretranslator creates a binary version of the module. These binary versions can be linked together using a consolidator program. The resulting linked binaries can then be run from the interpreter, bypassing the PDSS environment. Both the consolidator and interpreter require the creation of a special file to tell the program which files will be needed for the execution of a program.

This mechanism is handy since it serves as a primitive make utility. Unfortunately, the pretranslator, consolidator, and interpreter write their more useful error messages into a listing file. The error messages that do come to the screen are not particularly helpful.

This arrangement is probably a legacy from mainframe programming. In these days of interactive computing, you should be able to send errors both to the screen and a listing file. Listing a file for just one error is inconvenient. There didn't seem to be a significant speed difference between programs run from PDSS and those that had been translated into binary.

A large number of environmental parameters can be set for both the PDSS environment and stand-alone programs. Perhaps the most useful of these is the parameter *evaluation_limit,* which determines the number of statements that will be evaluated in trying to instantiate a goal. This parameter is very useful in protecting against runaway programs and is certainly more effective than trying to interrupt a program with Control-C.

MPROLOG is somewhat compatible with Clocksin and Mellish, though not completely so. (A version of PDSS, PDSS10, supports the standard predicates but doesn't support building stand-alone programs.) The principal differences between MPROLOG and straight Clocksin and Mellish implementations are that *assert* and *retract* are replaced by *add_statement* and *del_statement,* respectively, and *functor* and *args* are replaced by a single Swiss-army-knife predicate structure. Also, *call* is replaced by *evaluate.* Considering that portability between operating systems is one of the goals of MPROLOG, I found these changes gratuitous.

I was less disturbed by the changes made for the purpose of file handling. MPROLOG uses the concept of a channel for all I/O. Unusually, some of the I/O input predicates have versions that are undone on backtracking. MPROLOG does support direct-access files.

On the PC, MPROLOG only comes in an interpreted version. (Apparently, there is a compiler for larger machines.) Response time is quite adequate in the development environment.

I ran most of the benchmarks without significant modification. I did have to reduce the number of asserts from 1,000 to 500 to avoid running out of memory. Also, the recursive list walker produced a heap overflow that left me without enough room to edit.

While I was running the benchmarks, I discovered that floating-point arithmetic is not supported on the PC. The documentation gives the impression that it is, but a call to Logicware confirmed it isn't. However, you can call an external Pascal or assembler program if you need floating-point arithmetic.

In addition to the manual and disks that come with the professional version, I received a copy of a tutorial package that covers the fundamentals of PROLOG, rather than the use of Logic-Lab. I experimented with it briefly and found it quite helpful but somewhat inflexible. The tutorial would provide a reasonable introduction to MPROLOG.

I would have liked more tutorial material for the main system. A tutorial on PDSS and several example programs would make it much easier to understand the PDSS environment. Logicware promises completely revised documentation with MPROLOG v. 2.2; perhaps a tutorial will be part of it—I hope so. The distribution disks do provide some ready-to-run modules, including sample graphics and cursor manipulation routines and

```
module test_b.

/* Check if Argentina and Australia are the two countries */
/* in the southern hemisphere whose capitals are at the   */
/* same latitude. */

export( geographical_question/Ø ).
import( capital/2 , location/3 ).
visible( argentina , australia ).

/*$eject*/ body.

geographical_question :-test(X,Y), X=argentina, Y=australia .
test(COUNTRY1,COUNTRY2) :- capital(COUNTRY1,CITY1),
location(CITY1,LAT,_), LAT<Ø, capital(COUNTRY2,CITY2),
location(CITY2,LAT,_), CITY1@<CITY2 .

endmod /* test_b */ .
```

Listing 2.

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list utilities.

The MPROLOG programming environment has many strengths to recommend it. The support for large programs is extremely good. The extensive support of modularity and information hiding do require a fair amount of time to get comfortable with; Logicware offers instructional seminars.

Everything you'll need to write high-quality PC applications is available, including graphics and support for exception handlers. Programs written in other languages (just Pascal and assembler currently) can be accessed. If command.com and your favorite editor are in the current directory, you can access DOS commands and the editor from within PDSS.

MPROLOG's weaknesses can all be traced to the laudable desire to make the package operating-system independent. As a result, the overall feel of the package is similar to mainframe programming rather than the more user-friendly atmosphere of personal workstation computing.

I found most of the error messages terse and uncommunicative. A typical response in the PDSS environment would be "XYZ wrong command —>." In spite of this, once I had adapted to the style of the package, it was quite pleasant to work with.

MPROLOG should be considered for large applications. It's reasonably close to the Clocksin and Mellish standard, and its limitations are few.—J.H.

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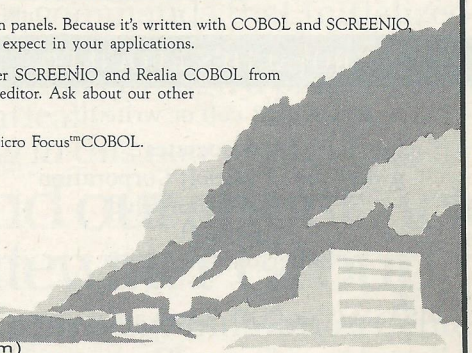

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The interpreter/compiler supports both the standard and Edinburgh syntaxes. PROLOG-2 provides a rich superset of the standard syntax features and complete access to the host-machine operating system.

The top-level listener is a dialogue consisting of queries, control predicates, and PROLOG programming statements. Debugging, editing, and error messages are provided in separate screen windows. Extensions of the DOS edit keys are available to the user; for example, F3 will retrieve the last command. Actually, PROLOG-2 maintains a small console stack making the last dozen or so commands available just by repeatedly pressing F3.

PROLOG-2's features are provided in discrete modules that can be included into the system at start-up time. Modules to support interactive editing, debugging, DEC-10 compatibility, a math coprocessor, grammar rules (definite clause grammar syntax), token processing, and on-line help are included by entering control statements into an initialization file. The initialization file is automatically consulted when the PROLOG-2 environment is started.

The PROLOG-2 system files are large and numerous; a hard disk is essential for efficient operation. You can successfully run PROLOG-2 from two floppy drives, although it's impossible for the floppies to hold both the help system and compiler at the same time.

The manual recommends that floppy drive owners make two copies of their system disks, one with the help system and the other the compiler system. The two systems can't be used concurrently during any one execution of PROLOG-2. It is possible to achieve reasonable (though not exceptional) performance from PROLOG-2 by using RAM disks. However, this advantage is only gained if the virtual memory is provided from any extended memory above the 640K recognized by DOS.

PROLOG-2 has an extensive vocabulary of built-in predicates that are compatible with the standard syntax. The full spectrum of arithmetic and comparison operators are available; transcendental functions are available only if the host machine is equipped with a math coprocessor. Multiple predicate declarations (functors with the same name but differing in arity) are allowed.

PROLOG-2 is one of the few PROLOG products that supports dot notation for lists. The dot is predefined as a prefix

operator with the following meaning: *.(a,b) <==> [a|b].*

The *op* predicate allows the dot to be defined as an infix operator. The dot operator is often seen in logic programming texts and is a feature of standard syntax that's rarely included in PC implementations.

Tail-recursive structures are predicates that call themselves; the recursive call is the last clause to succeed before a predicate is satisfied. A tail-recursive structure can be transformed into an iterative structure that doesn't require recursion.

By default, PROLOG-2 automatically optimizes to eliminate tail recursion, altering a program's backtracking. Tail-recursion optimization can be turned on or off by setting one of the PROLOG-2 state switches. Tail-recursion optimization is always on during compilation.

PROLOG-2 uses the standard *tell, telling, told, see, seeing,* and *seen* syntax in its file handling. It also supports creation of user-defined windows and I/O streams. PROLOG-2 manipulates random-access files and formatted input and output; bit-mapped graphics are not supported.

Operating system access is provided at two levels. PROLOG-2 has built-in predicates for many MS/PC-DOS commands. Commands are available for changing the logged drive or directory paths; creating or removing a directory; determining file sizes; and erasing, re naming, and determining the existence of files. The predicate *command/2* passes commands to the DOS command processor.

The operating system is also available from a separate host session window. The auxiliary session is invoked by a call of the form *command(_,N),* where *N* is bound to an integer. When a DOS session is finished, you can return to PROLOG-2 by typing *exit* at the DOS command prompt. The integer required in the *command* predicate specifies how much memory is to be freed by PROLOG-2 when it invokes the command.

PROLOG-2 claims all available system memory when it's running. Before it can invoke the auxiliary command processor, it must free up some of this memory by writing parts of itself out to disk. Since saving to disk is time-consuming, the user is given the option of choosing how much memory to free.

Unfortunately, when the *command* predicate is used in conjunction with session logging, an insidious bug crops up. Session logging allows a PROLOG-2 dialogue to be echoed into a file. The bug occurs when you start session logging, call an auxiliary DOS session, change the default drive, and then exit back to PROLOG-2.

Upon your return, PROLOG-2 fails to recognize the switch in drives. It continues to log the session, but it does so with the open file handle of the original drive. The results of this can be disastrous.

The first time this bug appeared, it wrote the session file onto the file allocation table (FAT) area of an unsuspecting floppy disk, completely and permanently trashing its data. The manual carries no warning about changing logged drives from an auxiliary session.

The effects of the bug can be avoided with appropriate care. By trial and error, I discovered I could assert an auxiliary clause to call DOS with the following definition:

```
new_command(YourSize) :-
        default_drive(X),
        command(_,YourSize),
        login(X).
```

This code saves the current drive, calls DOS, and then restores the current drive when it's finished. Apart from this one avoidable bug, PROLOG-2 appears to perform exceptionally well.

For PROLOG program development, debugging is extremely important. To use the trace facilities, the debugger system files must be loaded from the initialization file. The debugging system offers a standard tracing facility and lint checker. You can debug by leashing ports, setting spy points, or using single-step tracing. When an error is encountered in a query, the editor is automatically invoked, and you have the option of correcting, tracing, or aborting the goal.

PROLOG-2 supports grammar rules by inclusion of a directive in the initiali-

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zation file. Grammar rule notation is a convenient representation for parsing sentences during natural language processing. When this feature is loaded, PROLOG-2 will automatically translate grammar rules into PROLOG clauses.

A similar feature is supplied for parsing tokens. Consider an input stream of a string of characters and numbers representing an arithmetic expression such as 3 + 5. Here, 3, +, and 5 are all tokens.

Using its token compiler, PROLOG-2 will create PROLOG clauses to recognize and parse constituent tokens from the stream. This facility is useful for developing a top-level PROLOG interpreter. The token and grammar facilities also provide convenient mechanisms for creating an expert system user interface.

PROLOG-2 supports modular programming, allowing efficient development of large-scale applications. The scope of predicates in individual modules can be controlled by declaring a functor either public or private. The private predicates' names are known only to the current module. Public predicates can be called by any module. The scope of a predicate can be changed dynamically (during execution of a program) with the built-in predicates *private(predname)* and *public(predname)*.

A single program or collection of modules can be compiled into what the manual calls assembly code, although the interpreter is still required for execution. Compilation is extremely slow, but the manual claims compiled files will execute five times faster than interpreted files. Once compiled, a program can't be altered or traced with the debugger.

External modules can be linked with compiled Lattice C and assembler code. C programs require an assembly language interface before they can be used by PROLOG-2.

For a modular programming project, a data module can be declared to reside in actual or virtual memory. This allows a program to exceed the size of actual system memory. Data modules are not well-defined in the users manual but presumably are collections of tailless assertions. When a module is in virtual memory, it will be swapped to and from disk when necessary. This facility increases the overall size of PROLOG-2 programs and makes them run more slowly.

The PROLOG-2 users manual is approximately 600 pages and packaged in two large ring binders. The manual contains an index, glossary, and 200-page catalogue of built-in predicates. The manual doesn't have a tutorial and assumes more than an elementary knowledge of PROLOG on another system.

Despite its girth, the manual is very poorly organized. Learning to use some of the features from the manual is like trying to learn a foreign language from a dictionary. It pays very little attention to how predicates work together; for its 600 pages, there are probably less than a dozen complete examples.

The treatment of built-in editor, windows, and streams suffers most from the lack of examples. Here's an example of the manual's presumptive tone from the "Opening Streams" section: "Opening a stream does not make it current. A stream must be made current before input or output can take place." How is a stream made current? There's no discussion of current streams; the manual's next topic is closing a stream.

Using the editor for the first time is equally frustrating. Again, there's no complete example of how to invoke it. The answers to these basic questions can only be gleaned through trial and error or technical support.

PROLOG-2 is distributed on five disks that hold the PROLOG-2 system, run-time modules, help system, compiler, and sample programs. In contrast to earlier releases, Expert Systems International has removed all copy protection.

Only a few sample programs are supplied. However, one of the programs is an impressive LISP interpreter written entirely in PROLOG. Examples of external C programs callable from PROLOG-2 are also provided.

PROLOG-2 is well suited for large-scale expert system development. It isn't cheap, but its performance and features make it worth the price.—J.V.

Borland International Turbo PROLOG

In the letter that comes with Turbo PROLOG, Philippe Kahn, the president of Borland International, explains that Turbo PROLOG is "the first PROLOG implementation for IBM PCs and compatibles to deliver a high level of performance while remaining conservative in its memory requirements." Apparently, Borland decided that the best way to do this was with a conventional compiler-type mechanism—a choice that has had a considerable influence in shaping the package's programming environment.

Following the approach taken in Turbo Pascal, Turbo PROLOG presents a complete environment for developing and running programs. The default screen provides four windows: an edit window for creating the program, a dialogue window for run-time communication with programs, a message window that tracks the progress of the current PROLOG session, and a debug window for tracing a program's execution. A user can reconfigure the windows permanently or just for the current session.

The system makes use of menus for such functions as loading files and examining directories. A typical session re-

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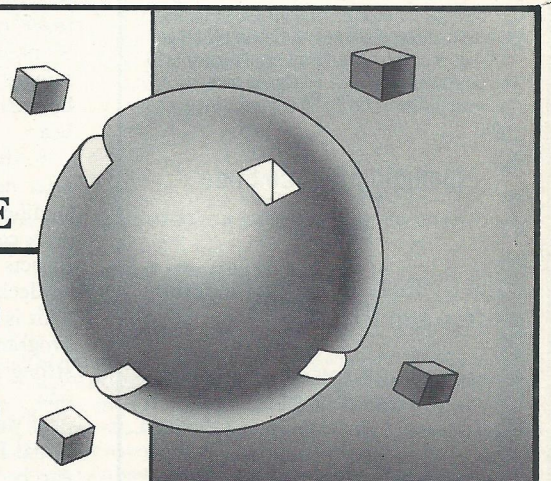

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quires loading a program file, followed by some editing; the program is then run from the top-level menu. Since Turbo PROLOG is compiled when a program is run, checks are made before any attempt to instantiate a goal. If the program fails any of these checks, control is passed to the editor with the cursor at the point where a check failed. This is a considerable convenience during program development; users of Turbo Pascal will be familiar with its advantages.

Although the manual claims that Turbo PROLOG conforms to the Clocksin and Mellish standard, there are significant differences between the syntax of the two—most of which can be attributed to the choice of a compiled language. Since these differences have been the subject of some debate, I'll spend some time discussing them so that you'll know what to expect from Turbo PROLOG. (For an earlier review of Turbo PROLOG, see "Inside Turbo PROLOG," AI Eye, *COMPUTER LANGUAGE*, July 1986, pp. 23-28.)

The most obvious difference is that Turbo PROLOG requires that all predicates be declared before they are used. I can illustrate this with Turbo's version of the member program (Listing 3). This example is taken directly from the program disk. I've added a goal to illustrate where it would appear in a complete program.

Domains are Turbo PROLOG's name for types; the standard ones are *char, integer, real, string, symbol,* and *file.* Symbols are handled differently from strings: they go into the symbol table, but strings are accommodated on the heap.

In the preceding code, the asterisk after *name* in the definition of *namelist* signifies that *namelist* is a list of names. As a consequence, predicates that handle objects from different domains need to be declared for each of those domains. This is an unfamiliar restriction in AI programming but, given the benefits of strong typing, perhaps not an unwelcome one.

If you're familiar with more conventional PROLOGs, you'll notice that *if* can be used instead of :-. *or* can also be used instead of a semicolon, and *and* instead of a comma. The manual's examples use both sorts but not within a single program. The use of *and, or,* and *if* does make programs more readable.

Turbo PROLOG's other major area of divergence from more conventional PROLOGs is its use of *assert* and *retract.* Only facts, not clauses, can be asserted and retracted. Predicates that are to be the subject of assertion and retraction must be declared in a special declaration section introduced with the reserved word *database.* Predicates that manipulate the data base must be typed so that they refer to the reserved domain *dbasedom.*

With this design, Borland has elected to view PROLOG as a language for data base access rather than a language for writing systems that learn new rules. Applications requiring intelligent data base access will benefit from the forthcoming Turbo PROLOG Toolbox, which is promised to contain predicates for file transfers from Lotus 1-2-3 and dBASE.

While this data base design does restrict the kinds of self-modification a program can do, it is in line with modern language theory. For similar reasons (related to the compilation method), you can't define operators and their precedence.

Most of Edinburgh PROLOG's other features are available in some way through the programming environment. Also, Turbo PROLOG provides numerous useful predicates not found in Clocksin and Mellish.

Turbo PROLOG has a very full set of predicates for file handling (although not the *see* and *tell* family). These predicates permit the creation and use of random access files by a PROLOG program. Predicates are provided for the manipulation of windows in both character and graphic modes—even turtle graphics.

You can invoke DOS commands and BIOS functions from a Turbo program and even link programs written in assembler, C, FORTRAN, or Pascal. (Ironically, since the current version of Turbo Pascal can't create .OBJ files, Turbo Pascal programs can't be linked to Turbo PROLOG programs. Borland promises to rectify this with Turbo Pascal v. 4.0.)

Some tools are available for modular programming. A project definition is a file with the names of modules to be linked together. Objects are shared between modules solely through the use of global domains and predicates, so there's only limited support for information hiding.

The Turbo PROLOG package comes with two disks and a manual. One disk has the PROLOG system, and the other has examples. Installation is straightforward. The manual's installation section

```
domains namelist = name* name = symbol predicates
member(name,namelist). goal member(jim,[fred,anne,jim]). clauses
member(Name,[Name|_]). member(Name,[_|Tail])
if member(Name,Tail).
```

Listing 3.

appears somewhat belatedly in chapter 12. If you're willing to accept the defaults, all you'll have to do is copy the system disk and type "PROLOG" at the MS-DOS prompt for the directory containing the system.

If you've never used PROLOG before, the manual has an excellent tutorial (with the understanding that this PROLOG is very different from conventional interpreted versions). All the programs in the text are also on disk, along with answers to the exercises. (A minor point: The C program and its driver in the text are not the programs on disk.) I ran several of the sample programs and found that they generally worked as advertised.

The manual's programmer's guide has a number of useful tips on programming style, several of them helpful in making programs more efficient. The compiler has some warnings built in that catch such things as variables that are only used once (you can ignore the warning if you want).

So how fast is Turbo PROLOG? The examples compiled in a matter of seconds. I didn't compile any large programs, so I can't report on that aspect.

As to speed of execution, Turbo PROLOG is fast. On the benchmark suite, performance on arithmetic predicates was particularly impressive.

The modification of the benchmark programs to run under Turbo PROLOG took some time. Many of the benchmarks have a large number of predicates, and while Turbo PROLOG will accept up to 500 predicates, adding declarations for 100 predicates was tedious. (Perhaps I should have written a PROLOG program to write the declaration sections automatically.)

Turbo PROLOG is a well-crafted package. Initially, I was somewhat resistant to Borland's compiler approach, its restrictions on handling predicates from different domains, and the inability to assert and retract rules. For certain AI applications, these would be real limitations.

On the other hand, for data base applications, these compromises are not serious and may in fact lead to better programs. The ability to link together separate modules and even access programs in other languages is desirable for writing large programs, although these features are somewhat marred by the requirement that shared predicates be global.

Turbo PROLOG provides a wealth of predicates beyond the usual Clocksin and Mellish ones, making the package a very attractive programming environment. The compiler approach does succeed in blending some of compilation's advantages with PROLOG's declarative strengths. Applications programmers can write the window-rich user interfaces

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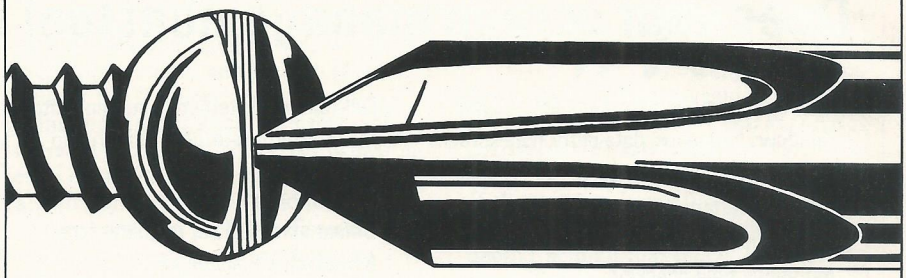

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that have become the norm for user-friendly programs.

One final note: the terms of the software license are written in admirably clear English. I'm not a lawyer, but I found the statement to be both generous and unambiguous. Borland is to be commended on this.—J.H.

Automata Design Associates VML PROLOG

VML PROLOG is an extensive, professional-level PROLOG system suitable for research and development. The system provides a rich programming environment with a large set of powerful and innovative extensions.

The package reviewed included a loose-leaf manual and four noncopy-protected disks. Versions of the interpreter are included for systems both with and without a math coprocessor. Example programs are included in compressed format.

Installation consists of copying the files to the destination directory and running a configuration program to set the amount of memory allotted to the interpreter workspace.

Though voluminous, VML PROLOG's documentation lacks the organization and structure you'd expect from a $200 product. Granted, it's difficult to present a coherent view of such an exhaustive series of functions and capabilities, but the inclusion of an index would be welcome.

VML supports a vast array of built-in predicates and operators, including bitwise operations, definite clause grammars, inference engines, and meta interpreters. This array of extensions is staggering, though at times oddly inconsistent in its coverage of a particular facility. For example, the set of bitwise operators does not include a shift operator, leaving you to perform arithmetic operations to achieve the desired effect. While this is a solution, it obscures the intent of a computation that would otherwise be lucid. This shortcoming is balanced by the innovative extensions VML makes to PC-based PROLOG.

One area of innovation is the introduction of global variables. While standard PROLOGs require that values to be maintained over successive goals be asserted into the data base, VML permits the definition of global variables that maintain their values. This saves time and reduces tedious bookkeeping.

Global variables are set using the infix *set* operator and can hold structures or numbers. Global variables can also be used to store arrays as actual arrays of memory locations rather than less space-efficient lists.

Very large values can be kept in special variables known as superatoms. Superatoms are functors whose names may be as long as 3,000 characters. Using superatoms, you can store entire screens, complete with cursor sequences, and display them by simply printing the value of the functor.

The standard PROLOG flow of control can be extended with an intriguing suite of VML predicates. *Cond,* a conditional form of *cut,* allows conditional removal of successful goals from the stack upon backtracking. Complementing *cond* is *repcond,* essentially a conditional *repeat* predicate. *if* and *repif* conditionally undo or repeat instantiations made by a successful goal.

The standard PROLOG data base model's flexibility is extended with domains. VML's domains are programmatic modules in which all external interactions must occur through a single predicate called the port. All other predicates are inaccessible to external domains.

Ports are either exports or imports, allowing predicates defined in the domain to be available to external callers or externally defined predicates to be available inside the current domain. This is analogous to Common LISP in the sense that it facilitates the modularization of PROLOG programs, allowing multiple programmers to work together with greater ease.

Domains are scoped in an inheritance structure, allowing lower-level (child) domains access to data and predicates in their parent domains.

VML has a well-thought-out virtual memory system that can overcome the PC's memory limitations. Virtual memory is available through the special *consultv* predicate. *consultv* caches portions of the data base in memory while retaining indexes to the rest of the data base, which is kept in an external file. This method allows data bases several times larger than available memory to be incorporated into a system with relative ease and only a small penalty in performance.

VML PROLOG includes an extensive set of IBM PC-compatible functions, including full keyboard, graphics, timer, and screen support. Timer support includes the implementation of an asynchronous timer interrupt, suggesting the intriguing possibility of background and foreground tasks and other sorts of multitasking. You can set a timer trap to transfer to a specified goal upon expiration of the timer. In cases when a desired DOS operation is not built-in, predicates are provided to generate the necessary interrupt instructions.

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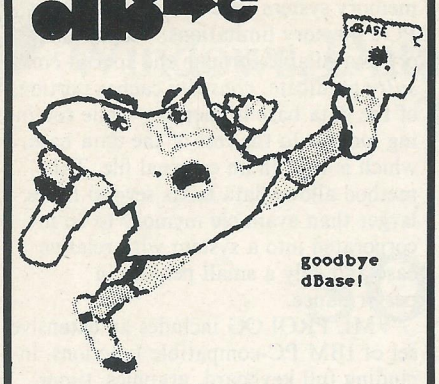

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Steven Engle is an artificial intelligence software engineer for Expert-EASE in Belmont, Calif. His interests include robotics, computer vision, and neural computing.

Jonathan Hodgson is a professor of math and computer science at St. Joseph's University in Philadelphia, Pa., doing research in operating systems and artificial intelligence.

James Vita is a programmer at City College of New York, New York, where he designs mainframe data base systems. He is currently completing his M.A. in computer science and is interested in object-oriented languages and computer vision.

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PROLOG benchmarks

While the benchmarks used for this wrap-up are not the last word on the subject of benchmarking PROLOGs, we believe they represent a step forward in the business of comparing PROLOG implementations on some logical basis.

Benchmarking was done on a Zenith AT-compatible running at 12 MHz. Chalcedony PROLOG/i, Cogent PROLOG, and VML PROLOG had timing mechanisms that were too crude to make accurate timings and are not included in the benchmarks table.

The benchmarks are set up as two files. One file (DRIVER.PRO) contains the routines that call and manage the invocation of the predicates in the main benchmark file (BENCHES.PRO). The main benchmark file has a total of 22 benchmark calls, producing 33 benchmark output messages. The benchmarks are designed so that the overhead time for invoking the predicate is deducted from actual execution time. Each benchmark was run for 200 iterations, except where otherwise noted in the table:

■ *Tail_call_atom_atom* tests the response in executing 100 determinate tail calls of the form:

```
p1(a) :- p2(a).
p2(a) :- p3(a).
p3(a) :- p4(a).
```

and so on to the last two lines:

```
p99(a) :- p100(a).
p100(a).
```

■ *Binary_call_atom_atom* mixes 63 determinate nontail and 64 determinate tail calls. The former calls look like this:

```
q1(a) :- q2(a),q3(a).
q2(a) :- q4(a),q5(a).
```

The determinate tail calls were simple PROLOG facts:

```
q76(a).
q77(a).
```

continuing to 127 total calls.

■ *Cons_list* constructs a 100-element list nonrecursively. The calls look like this:

```
r1([1|R]) :- r2(R).
r2([2|R]) :- r3(R).
```

and so on to the final call of

```
r101([]).
```

■ *Walk_list* performs a nonrecursive walk down a 100-element list.

■ *Walk_list_rec* walks down the same 100-element list recursively.

■ The sixth benchmark is one of the most rigorous. It requires a recursive walk down 100, 200, 400, 800, and 1,600 copies of a 100-element list. In the tables, these timings are given under the heads of *args(1)*, *args(2)*, and so forth.

■ *Cons_term* nonrecursively creates a term with 100 nodes. The calls look like this:

```
s1(f(1,R)) :- s2(R).
s2(f(2,R)) :- s3(R).
```

and so forth until 100 nodes are constructed.

■ *Walk_term* performs a nonrecursive walk down the 100-node term constructed in *Cons_term*. *Walk_term* does the same walk recursively.

■ *Shallow_backtracking* analyzes the quality of shallow backtracking.

■ *Deep_backtracking* tests the deep backtracking speed.

For both *shallow_backtracking* and *deep_backtracking*, the benchmarks assume no indexing takes place on the second argument. Both use a consistent fact list of 100 elements, similar to:

```
b(_X, 1).
b(_X, 2).
```

and so forth.

For the shallow backtracking test, the call to this set of facts is:

```
shallow :- b(_X, 100).
```

and for the deep backtracking, it looks like this:

```
deep :- b(_X,Y), Y=100.
```

■ *Choice_point* pushs 100 choice points onto a PROLOG's stack with a simple but elegant program set:

```
c1(a) :- c2(a).
c1(a).
c2(a) :- c3(a).
c3(a).
```

■ *Trail_variables* tests the ability to manage trail variables, generally part of memory management. The benchmark creates 100 choice points and trails 100 variables with code similar to:

```
trail :- t1(X), !
t1(a) :- t2(_X).
t1(b).
t2(a) :- t3(_X).
t2(b).
```

This process repeats until 100 points and trail variables are generated.

■ *Medium_unify* and *deep_unify* test the unification of terms that are spatially small but textually quite large.

■ *Integer_add* performs 100 integer additions nonrecursively. The benchmark avoids calls that would give compilers with certain optimizations an unfair advantage. Here is a sample line from the predicate list:

```
a1(M, K, P) :- N is M + K,
      a2(N, 2, P).
```

■ *Floating_add* is essentially the same as *integer_add* but uses floating-point math instead.
■ The 17th benchmark tests the integrity of the benchmarks with 100 calls to an argument located at the first, second, fourth, eighth, and 16th positions in a complex term. If the benchmarks are running properly, timings should vary little (if at all) across positions within an implementation. Results are listed under *arg(1), arg(2),* and so forth.
■ *Index* performs 100 indexed calls, indexing on the first argument. The first few lines of code look like:

```
ix(1) :- ix(10000).
ix(4).
ix(9) :- ix(4).
ix(16) :- ix(9).
```

■ *Assert_unit* asserts 1,000 unit clauses. *Access_unit* then accesses 100 dynamically created clauses with the first argument instantiated.
■ *Slow_access_unit* does the same thing as *access_unit* but with the second argument instantiated, a substantially slower process.
■ The last benchmark tests the quality of the implementation of *setof* and *bagof* with the special test *double_bagof*. Here's the code for these tests:

```
bench_mark(setof, 10, setof
      (X, Y^pr(X, Y), S),
   dummy(X, Y^pr(X, Y), S)).
bench_mark(bagof, 10, bagof
      (X, Y^pr(X, Y), S),
   dummy(X, Y^pr(X, Y), S)).
bench_mark(double_setof, 10,
   setof((X,S), setof(Y, pr(X, Y), S), T),
   dummy(S, setof(Y, pr(X, Y), S), T)).
```

The benchmarks for this wrap-up were written primarily by Fernando C.N. Pereira, Ph.D., of SRI International in Menlo Park, Calif. Having worked with PROLOG since 1975, Pereira is a seasoned PROLOG designer, implementer, and programmer.

The concepts behind these benchmarks are the product of many peoples' work and views. Pereira wishes to acknowledge the contributions of Richard O'Keefe, Paul Wilk, and David Warren to the field of PROLOG benchmarking. The complete benchmark suite is available from the *COMPUTER LANGUAGE* Bulletin Board Service and CompuServe Forum.

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Benchmarks (milliseconds)

Manufacturer and product	Tail_call_atom_atom	Binary_call_atom_atom	Cons_list	Walk_list	Walk_list_rec	Args (1)	Args (2)	Args (4)	Args (8)	Args (16)	Cons_term	Walk_term	Walk_term_rec	Shallow_back_tracking	Deep_backtracking
Applied Logic Systems ALS PROLOG	1.90	3.50	3.30	2.75	2.50	2.75	4.40	7.65	14.85	—[1]	3.25	3.00	3.05	3.05	9.60
Arity Arity/PROLOG	69.55	399.05	957.00	971.35	75.80	74.90	88.60	112.60	166.40	270.50	70.60	75.50	73.90	56.90	130.90
Logicware MPROLOG	21.0	26.0	25.0	31.0	46.0	47.0	58.0	81.0	127.0	218.0	25.0	31.0	—[2]	16.0	62.0
Expert Systems International PROLOG-2 Professional	23.0	31.3	37.6	37.6	51.9	52.4	68.9	101.0	163.9	290.8	33.5	37.3	51.9	17.6	51.9
Borland International Turbo PROLOG	1.50	1.70	3.40	not run	not run	not run	not run	not run	not run	not run	not run	not run	not run	184.00	23.50

Manufacturer and product	Choice_point	Trail_variables	Medium_unify	Deep_unify	Integer_add	Floating_add	Arg (1)	Arg (2)	Arg (4)
Applied Logic Systems ALS PROLOG	5.20	6.05	3.05	190.70	8.47	164.90	—[1]	—[1]	—[1]
Arity Arity/PROLOG	380.60	65.90	2.70	190.60	176.20	459.79	159.80	159.85	159.90
Logicware MPROLOG	25.0	31.0	7.0	468.0	116.0	—[3]	159.0	159.0	159.0
Expert Systems International PROLOG-2 Professional	27.2	25.0	05.7	381.2	109.6	118.1	94.5	97.7	104.3
Borland International Turbo PROLOG	12.00	not run	not run	not run	1.70	10.00	not run	not run	not run

Manufacturer and product	Arg (8)	Arg (16)	Index	Assert_unit	Access_unit	Slow_access_unit	Setof	Bagof	Double_bagof
Applied Logic Systems ALS PROLOG	—[1]	—[1]	6.60	2,420.00[4]	6.10	17.00	275.00	10.00	719.00
Arity Arity/PROLOG	160.10	176.90	237.00	15,930.00[4]	6.60	231.00	not run	not run	not run
Logicware MPROLOG	159.0	163.0	1,241.0	19,500.0[4]	25.0	77.0	not run	not run	not run
Expert Systems International PROLOG-2 Professional	116.7	143.1	1,552.1	9,010.0[4]	32.4	89.0	—[5]	—[5]	—[5]
Borland International Turbo PROLOG	not run	not run	10.00	610.00[4]	not run	not run	not run	not run	not run

1. Benchmark failed due to too many parameters in predicate.
2. Benchmark failed due to heap or stack overflow.
3. Benchmark failed because floating-point math was not supported.
4. Only PROLOG-2 Professional supported the full 1,000 asserts in *Assert_unit*.
5. Benchmark yielded invalid results; the test time reported was less than the control predicate time.

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Arity Arity/PROLOG	yes	no	trace	no	yes	no	few	no	phone	yes	yes	yes	yes	sep.	C, FORTRAN, Pascal
Chalcedony Software PROLOG/i	no	yes	trace	no	yes	yes	few	no	users group	no	no	yes	yes	yes	C, Pascal
Cogent Software Cogent PROLOG															
Interpreter	no	no	trace	no	ST	yes	yes	no	phone	no	yes	yes	yes	yes	no
Compiler	yes	no	trace	yes	ST	yes	yes	yes	phone	yes	yes	yes	yes	yes	no
Logicware M PROLOG	no	yes	trace	no	yes	sep.	few	no	phone	yes	yes	yes	yes	no	Assembler, C, Pascal
Expert Systems International PROLOG-2 Professional	no	no	trace	yes	yes	no	yes	yes	phone	yes	yes	yes	yes	no	Assembler, C
Borland International Turbo PROLOG	yes	yes	trace	yes	yes	yes	yes	yes	phone	yes	yes	yes	yes	sep.	Assembler, C, Pascal
Auomata Design Associates VML PROLOG	no	no	trace	no	yes	brief	yes	no	phone	no	yes	yes	yes	no	no

Sep. = Separate.
ST = Simple text.

Programming support

Manufacturer and product	Stand-alone programs	Interactive execution	Supports modular programming	Clocksin and Mellish compatible	Exception handling	Predicate indexes	Source code for built-in predicates	Dynamic rules	Grammar rules	Tail recursion optimized	Garbage collection	Floating-point numbers	Minimum memory
Applied Logic Systems ALS PROLOG	yes[1]	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	512K
Arity Arity/PROLOG	yes	yes	no	yes	no	yes	no	yes	yes	yes	yes	yes	512K
Chalcedony Software PROLOG/i	no	yes	no	yes	no	no	no	no	no	no	yes	yes	256K
Cogent Software Cogent PROLOG													
Compiler	yes[1]	yes	no	yes	no	yes	no	yes	yes	no	yes	yes	256K
Interpreter	no	yes	no	yes	no	no	no	yes	no	no	yes[2]	no	256K
Logicware MPROLOG	yes[1]	yes	yes	yes[3]	yes	no	no	yes	yes	yes	yes	no	512K
Expert Systems International PROLOG-2 Professional	yes[1]	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	384K
Borland International Turbo PROLOG	yes[4]	yes	yes	no	no	no	no	no	no	yes	yes	yes	384K
Auomata Design Associates VML PROLOG	yes[1]	yes	yes	yes	limited	no	no	yes	yes	yes	yes	yes	512K

1. Programs require run-time system to be run separately.
2. Garbage collection is manually initiated.
3. Clocksin and Mellish compatible in DEC-10 mode.
4. Stand-alone programs available as .EXE files.

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LISP PC products: Survival of the species

By Julia Hodges, Jon Roland, and Richard Parke

Some of the most creative programming done on computers today is in LISP. The variety of LISP projects is reflected in the different approaches to the language's implementation on the microcomputer.

The following are reviews of a diverse collection of microcomputer LISPs. The products covered are ExperTelligence's ExperCommon LISP, Gold Hill Computers' Golden Common LISP, Integral Quality's IQLISP, ProCode International's Waltz LISP, Soft Warehouse's muLISP-86, Sapiens Software's Star Sapphire LISP, and Solution Systems' TransLISP.

Some of the packages offer features that make them uniquely suited for particular purposes. One has a LISP-to-C compiler, which, so far as we know, is the first such product in commercial distribution. Two of the packages implement large subsets of the Common LISP standard.

Among the packages is muLISP, one of the oldest microcomputer LISP implementations. muLISP is generally accompanied by the muMATH package of math functions. For a long time, these functions offered almost the only convenient way to do symbolic math and infinite-precision arithmetic on a micro.

Not everyone agrees that LISP should be the language of choice for commercial AI development or even prototyping. For commercial products, C has emerged as the language of choice.

PROLOG is considered an AI contender, especially as more mature versions emerge. A new language, NIAL, overcomes some of the disadvantages of older languages like LISP and APL, and new versions of Forth are taking their place in some serious applications.

The winners of this debate are programmers and the users of the programs they write. Innovations in one language rapidly spread among the others. Concepts like incremental memory compilers and object-oriented programming that were once thought exotic are now accepted as useful and powerful tools for improving programmer productivity and product quality.

Whether LISP ultimately survives is perhaps less important than the innovations that are being pioneered in LISP today. In virtually every area, important work is being done in LISP. Here are some of the packages that can let you join the fray.—J.R.

ExperTelligence ExperCommon LISP

ExperTelligence's ExperCommon LISP is an implementation of a large subset of Common LISP for the Apple Macintosh. As a product for the Mac, it uses the machine's operating system and toolbox to good advantage.

Although applications can be delivered on a Macintosh with only 512K RAM, the system requires at least 1MB to run. I reviewed ExperCommon LISP on a Macintosh SE with 1MB RAM and a 20MB hard disk.

The package's two main programs fit on a single 800K disk, but there is so little space left that a hard disk is required for any real programming. The first program, ExperCommon LISP, contains the LISP kernel and creates the programming environment. The second, ECL Compiler, compiles LISP programs (called forms) into an area of memory called the listener buffer. The compiler can be loaded manually or automatically on boot-up; loading takes about 2 minutes. The main disk also has a configuration file for allocating system resources.

When the package starts up, the screen is divided into two windows. The upper half of the screen is the listener window where single-line LISP forms can be entered, compiled, and executed. The lower half is the edit window where multi-line LISP forms can be entered and edited but not executed. Both windows can be resized with the mouse.

LISP forms are written by entering the name of the compiled form and any necessary arguments in the listener window. By default, the results of execution are displayed in the listener window below the program line.

ExperCommon LISP differs from most microcomputer LISPs in several ways. First, there is no file interpreter. Most LISP packages consist of a file interpreter and perhaps a file compiler. ExperCommon LISP has a file compiler available as an option, but the main compiler is an interactive incremental memory compiler.

The incremental memory compiler compiles source code from one or more edit buffers into 68000 native code. The code resides in the listener buffer and can be accessed through its window. In this, ExperCommon LISP is similar to Texas Instruments' PC Scheme, Q'NIAL, and most versions of Forth and APL, which use an area of memory to hold the results of compilation and program execution.

You can compile all of your forms to the active edit buffer or highlight one or more with a mouse and just compile those. Forward referencing is permitted within a group of forms. However, before referencing a user-defined form you must have previously compiled it during the session. Any forms that have been compiled can be referenced; forms can be recompiled independently. One feature lacking is the ability to save the listener buffer to a file with all forms and variable bindings intact, a feature that would be helpful during development.

The edit window's editor blinks matching parentheses. Using the blinking parentheses and a mouse, you can mark a block of text for copying, moving, or deleting. Checking for unpaired parentheses is more difficult, requiring you to place the cursor on each parenthesis and then scan for a matching one blinking somewhere else.

Since ExperCommon LISP doesn't support paging or overlaying large programs, available memory limits program size. The current version of ExperCommon LISP can use up to 4MB. The version for the Macintosh II is expected to support more memory and the complete Common LISP standard.

The file compiler is distributed as a separate option. With the ResEdit facility, you can use the file compiler to create stand-alone programs. The stand-alone programs contain a copy of the ExperCommon LISP kernel but don't require the large amount of memory used by the

LISP environment. The minimum size of stand-alone programs is about 100K; they can be distributed without royalties.

You have to write your own user interface, but facilities are provided to use the entire Macintosh Toolbox. A separate product, the ExperInterface Builder, can be used to interactively generate interfaces without familiarity with the Macintosh Toolbox internals.

Almost all of the often-used Common LISP features are implemented; multidimensional arrays and handles are supported. The only features I missed were the *BIGNUM* data type and support of the *INITIAL-ELEMENT* keyword by the *MAKE-ARRAY* function.

ExperCommon LISP goes beyond the Common LISP standard by supporting object-oriented programming. The package's support goes beyond that of LOOPS and Flavors, more closely resembling Smalltalk-80. Over 600 classes support the more than 700 Macintosh Toolbox functions. However, ExperCommon LISP does not support multiple inheritance, only linear inheritance, but multiple inheritance is seldom used by most LISP programmers.

The Gabriel benchmarks I ran gave acceptable results, even though I didn't edit the configure file to optimize the use of available memory. More than half of the compilation and execution time was taken up by garbage collection. With more memory and an edited configure file to take advantage of it, compile and execution speeds could probably be reduced by a factor of three. ExperTelligence claims that v. 2.2's garbage collector is four times faster than v. 2.1's.

A more interesting claim I couldn't confirm is that ExperCommon LISP on the Macintosh II often outperforms Common LISP on the Symbolics 3600. For floating-point operations, ExperCommon LISP is said to be faster by a factor of five since it makes use of the 68881 floating-point processor, which is not available on the Symbolics 3600. If true, this level of performance could make the Macintosh II the system of choice for both research and commercial use.

ExperCommon LISP's documentation is excellent. It does not include Guy Steele's *Common LISP: The Language* (MIT Press, 1984), but the main package's two manuals and a third manual that supports Macintosh Toolbox development are well suited for learning Common LISP or application development on the Macintosh.

I'd like to see more sample programs. Public-domain code is available, but it will need to be rewritten to some extent. Examples of converting between versions of LISP would be useful. Also, while ExperCommon LISP's debugging facilities are excellent, the documentation does not go into sufficient detail on interpreting or responding to some of the error messages.

ExperCommon LISP is an excellent package for learning Common LISP and developing serious applications. It implements most of Common LISP and provides satisfactory performance on a 1MB Macintosh, but for full Common LISP or more serious applications I recommend a Macintosh II with plenty of RAM. In addition, ExperCommon LISP provides a good introduction to the Macintosh Toolbox and object-oriented programming.—J.R.

Gold Hill Computers
Golden Common LISP

Gold Hill's Golden Common LISP (GCLISP) is a Common LISP programming environment for the IBM PC and 100% compatibles. GCLISP is designed for use by both novice and experienced LISP programmers.

The package includes the GCLISP interpreter, which implements a major subset of Common LISP; the San Marco LISP explorer, an on-line interactive tutorial; and GMACS, a full-screen text editor with debugging facilities that's modeled along the lines of the EMACS editor.

GCLISP provides on-line help facilities for every function and variable. Two books are also included with the package: the second edition of *LISP* by Patrick Winston and Berthold K.P. Horn (Addison-Wesley, 1984) and *Common LISP Reference Manual* by Guy L. Steele Jr. (Digital Press, 1984).

GCLISP requires 1MB of memory. At least this much memory must be available for GCLISP to be installed on a hard disk.

The interactive tutorial is excellent. While it is far too detailed for the experienced LISP programmer, the simple explanations, many examples, and use of graphics make it an excellent teaching tool. You don't have to go through the entire tutorial; provision is made for jumping around. Your progress through the tutorial is logged when you exit.

The debugging facilities are also excellent. On-line help allows the programmer to list the arguments required for a given function, check the meanings of special keys, and refer to the documentation on various functions.

The package includes the usual *break, step,* and *trace* found in most Common LISPs. If you use *break* or if an error occurs during a function's execution, a new listener level is created. At the new level, you have access to all the services available at the top level. You can return from this new level with the function *clean-up-error* or you can try to track down the bug with the *backtrace* function, which lists all GCLISP forms that have not yet finished.

The implementation is a substantial subset of Common LISP. The only Common LISP feature notably missing is the *eval-when* function, which allows pieces of code to be executed at compile time only, load time, or when code is interpreted. The function's absence doesn't pose a significant problem since its use is quite limited and has few practical applications.

GCLISP evaluates functions as soon as the last right parenthesis is typed—there's no need to press the Enter key. Execution speed for functions is quite impressive.

This is an excellent package for both novice and veteran LISP programmers. The on-line tutorial will be appreciated by the beginner. The speed of execution, excellent debugging facilities, and Common LISP facilities make GCLISP a good choice for anyone shopping in the LISP market.—J.H.

Integral Quality
IQLISP

Integral Quality's IQLISP is designed to take full advantage of the IBM PC's features for the development of complex systems. With its speedy development, testing, and debugging of programs, IQLISP is well suited for applications that must be built quickly.

In general, IQLISP provides a good LISP environment. Once you get accustomed to how the system operates, program development is a very comfortable process. A variety of I/O functions are included, among them formatted I/O, command-line arguments, and windowing capabilities.

Many of the DOS functions (*DIR, CHDIR, MKDIR,* and the like) can be accessed from IQLISP. For scientific applications, IQLISP provides most of the commonly used mathematics functions, such as *SQRT, SIN, COS, ABS,* and *ATAN,* as well as math coprocessor support.

The package includes an editor that can be used within the LISP environment, which can be quite convenient during program development. However, the editor is a command-driven, object-oriented LISP editor and somewhat difficult to use due to a rather limited set of commands.

For debugging, a diagnostic package includes the usual LISP facilities like *trace* and *break*. An error monitor allows easy examination of the stack when an error condition occurs. This utility is similar to GCLISP's backtrace utility.

A highly unusual feature of IQLISP is the inclusion of structured programming macros. These macros (*FOR, REPEAT,* and *LOOP*) make it easy to use iteration

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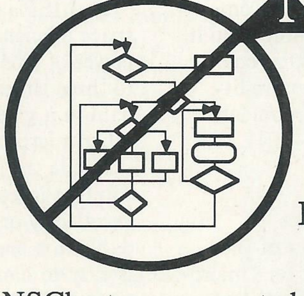

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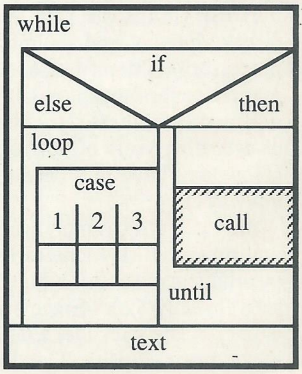

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when recursion isn't practical.

An on-line help facility documents the use of the various LISP primitives. Basically, the help facility only provides syntactic information about various functions. For example, *(HELP ASSOC)* causes the system to respond with *(ASSOC <ITEM> <LIST>)*.

Surprisingly, IQLISP is case sensitive to uppercase. This makes it awkward for those who've used Franz LISP, which is case sensitive to lowercase. This design is an unnecessary inconvenience.

The documentation is quite poor. Information isn't arranged to be easily available—the major problem is the indexes. There are indexes at the end of selected chapters, but there's no comprehensive index. To find an item, you must make an educated guess as to which chapter contains the information you need and then check that chapter's index (if indeed it has an index). A comprehensive index should be added; as presently organized, the manual is entirely too difficult to use.

The manual also lacks documentation on installing the system. The system requirements section has one paragraph that instructs you to insert the IQLISP disk containing the IQ.EXE file and type *IQ*. There is no further documentation. Users of hard disk systems are left to their own devices in determining what actions are appropriate. Although loading the system is not difficult, the lack of documentation is a major oversight.

IQLISP makes no claims about being compatible with either Franz or Common LISP. Once you're accustomed to it, IQLISP provides a good working environment, but the lack of compatibility with better known LISP environments detracts from its desirability.—J.H.

Soft Warehouse
muLISP-86

muLISP (mu is the 12th letter of the Greek alphabet and a symbol for "microprocessor") is described as a high-performance, general-purpose LISP system for personal computers. It is the culmination of over nine years of development effort. (How long have PCs been around, anyway?)

muLISP is extremely well packaged and presented. It includes features found in products with much higher prices but sells for only $250. Since a good tutorial is part of the package, LISP knowledge is not a prerequisite. The documentation includes references not only to AI books and periodicals but professional societies as well. muLISP is known for its speed—an important, albeit not all-important, consideration for potential PC LISP purchasers.

According to Soft Warehouse, muLISP provides "over 400 functions, special forms, macros, and control variables. Over 260...are in machine language for maximum efficiency." Infinite-precision integers and adjustable-precision rational arithmetic are supported. The two-pass garbage collector typically takes 2 seconds to complete. Dynamic memory reallocation is done within the 512K limit.

muLISP's kernel is small; 128K is the minimum RAM required. Extremely fast execution speeds have been achieved through shallow variable binding, address-typed data structures, and a closed pointer universe.

For your money, you get a lean, mean LISP interpreter, a debugger with trace and statistics, an editor, an optional compiler, demonstration programs, a tutorial, and utility libraries for Common LISP and InterLISP functions. *CATCH, THROW, UNWIND, PROTECT,* and sequential or random file access are notable additional features.

As for performance, the product installs quickly and initializes with blazing speed. I never broke an advertised feature; the whole product-pounding process was characterized by a growing appreciation of muLISP's speed. I was tempted to bring it up on my portable PC (which runs Microsoft's Windows at glacial speed) just to gloat at how muLISP can scream even on an antique. On a Compaq 286, it breezed through the Towers of Hanoi puzzle, even with 13 rings.

muLISP's other big strength is its space efficiency. The package has the power of Common LISP and stores two to three times as much program and data in a given amount of memory as other microcomputer LISPs.

While the documentation is a little wanting in color and visual variety, it is excellently organized and eminently readable in a small, convenient binder that is easy to handle. The primitive definitions include examples, a disturbingly frequent omission from many language products.

On the downside, muLISP uses only 512K of memory. Since DOS can address 640K, and serious artificial intelligence programming relies upon massive data stores, I wonder why Soft Warehouse stopped at 512K.

I was impressed with muLISP as a conservative, disciplined LISP for the PC. It is quite fast. Soft Warehouse's advertised benchmarks are, of course, unabashedly slanted toward its products with programs that don't ask for too much memory. A beginning LISP user should have no trouble learning and using muLISP, and the experienced user will take some time to outgrow the package.

I unhesitatingly recommend muLISP-86 as a sturdy, efficient interpreter/compiler. muLISP-86's successor, muLISP-87, is now available and is said to support more functions and forms as well as object-oriented programming with a Flavors package.—R.P.

Sapiens Software
Star Sapphire LISP

Sapiens Software's Star Sapphire LISP offers two unique features: a LISP-to-C compiler and a virtual 8MB address space. In addition, Sapiens advertises access to all Common LISP functions.

Using Star Sapphire definitely requires knowledge of LISP. Unlike other micro LISPs, Star Sapphire does not have a tutorial. Instead, it is designed for the experienced programmer, especially with its C support. The programmers guide displays an unabashed attitude of respect for the user as a serious programmer willing to dive into the product and grapple with issues of LISP and C internals.

Star Sapphire offers the first LISP-to-C compiler on the IBM PC. Many major software vendors are joining the performance-minded crowd that is reimplementing in C, among them SAS Institute and Teknowledge. A typical AI application is prototyped and developed in LISP, then the lean, stripped run-time package is marketed in C. Star Sapphire astutely follows that trend.

The virtual memory design acknowledges that any truly smart system will likely need of lots of code and data in memory rather than clever, tight algorithms. This is especially true for LISP with its demons, blackboards, semantic networks, and knowledge bases. In my opinion, any LISP that doesn't support lots of memory is suspiciously toylike.

I brought up Star Sapphire with Borland International's Sidekick resident and was startled to see the message "virtual memory error #7921 : xxx near line 0." After I kicked out Sidekick, Star Sapphire came up fine; it does take a good 20 seconds for the run-time environment to come up. The run-time development system affords "the capability of building interpreters with a smaller number of functions than a full LISP and incorporation of any C or assembly routine in the interpreter."

This is a welcome and forward-looking attitude. Coding is best done in the language most suitable to a job. Stubborn adherence to a single language is counterproductive.

Virtual memory can be configured for the number of pages and megabytes of virtual memory. By default, megabytes 0-2 are LISP *CONS* space, and 2-4 are atoms (data). Megabytes 4-8 are the virtual heap. Specific workspace addresses can be accessed with the *VSTORE* and *VFETCH* functions.

The disk label bears the trademarked

legend "A Common LISP compiler for the IBM PC." The package's developers are clearly ambitious and very serious. Offering a virtual 8MB, a run-time environment, and a LISP-to-C compiler are signs of a company with big plans.

However, the product is on shaky ground with its documentation. The documentation is poorly thought out with regard to getting you the information you need, and its coverage of many issues is less than thorough. For example, the section on nonrecoverable LISP errors says that the fatal error function is "vectored to" as a result of "munged virtual strings" and "impossibly incorrect input."

For the review, I received a programmers guide to Star Sapphire, which was run off on a dot-matrix printer and stapled. The text was not paginated, was too chatty for my taste, and had several spelling errors. Sapiens states that a functional specification of Star Sapphire is available; it is deferred to as the exhaustive reference.

This is an intelligently constructed product that is still growing. For the price, its unique features keep Star Sapphire LISP among the contenders. The product suffers in delivery and appearance, but its strong promise may make up for that.—R.P.

Solution Systems TransLISP

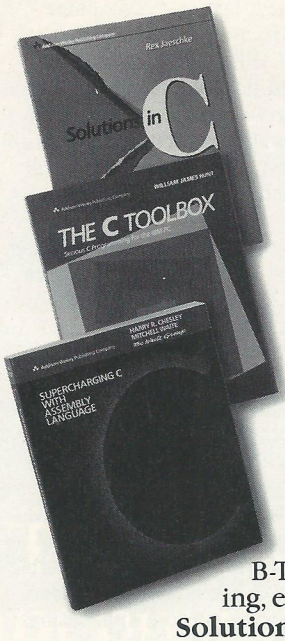
David Betz's XLISP floated around the public domain for a while as a small LISP with object-oriented programming support. Solution Systems' TransLISP is kind of a grown-up XLISP. The system is for the nonsophisticate who wants to really enjoy the product on his or her PC, and that's a breath of fresh air.

TransLISP is a nice, solid Common LISP-compatible interpreter for the novice LISP programmer. No more knowledge of LISP is assumed than can be garnered by reading the included tutorial.

The package has lots of demo programs that are designed to be both enjoyable and instructional. They serve nicely as a coding point of departure for the novice programmer who wants to see how things are done by examining a working program.

I had fun interacting with the Job Counselor program, drew some graphic shapes, and invoked the tiny PROLOG interpreter. Solution Systems wants you to enjoy its product, an attitude that isn't everything but is rare enough these days.

TransLISP's editor can be invoked from within or outside of the interpreter. Of course, it's best to edit while in the interpreter where you can execute what you just edited. To use the editor, be prepared to learn a fairly large set of special keys, key sequences, and key chords. The editor can even be used on non-IBM-compatibles.



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The product installs quickly and comes up fast. As long as I stuck to the book, the system never bombed. The manual gives a 10-page, point-by-point comparison of TransLISP to Guy Steele's Common LISP, even providing section numbers from the Common LISP book. There are quite a few "not supported" disclaimers, but this product isn't billed as a big-time LISP interpreter, after all. I didn't find any incompatibilities between TransLISP and Common LISP, but I didn't look very hard.

TransLISP's main strength is its accessibility to the novice. The documentation is delightful and includes an exhaustive index, a LISP-C-Pascal-BASIC language comparison, and a LISP bibliography. I was pleased to see an interpreter for a heavyweight AI language that's targeted at the growing number of PC owners who need a starting point somewhere and for whom confidence and comfort are essential.

Of the products I covered, TransLISP was the most fun to use and review, mainly because the book is good stuff. The package is for the novice to play with and learn LISP from on a personal computer. TransLISP begs for buyers' well-deserved attention with a Borland-like cheeriness. TransLISP was recently joined by TransLISP PLUS, which sells for $100 more.—R.P.

ProCode International Waltz LISP

ProCode International's Waltz LISP is intended to be a fast microcomputer LISP. The system comes with a full set of Common LISP functions, including such advanced flow-of-control features as *catch* and *throw*. It also has error-handling routines that allow you to interrupt a program at any time, do tracing and debugging, and then resume program execution.

I reviewed the 16-bit version of Waltz LISP; an 8-bit version that runs under CP/M-80 v. 2.0 or higher on a Z80 processor and at least 48K RAM is also available. Although both the 16-bit and 8-bit versions are capable of running in modest amounts of RAM, ProCode recommends more memory for serious development.

The package includes a full-screen editor that's WordStar-compatible. Waltz LISP's ability to handle text files and certain other features make it a suitable programming environment for the development of general-purpose applications (in addition to the AI applications normally associated with LISP). For example, Waltz LISP has a full set of string operations, including a powerful pattern-matching function.

With Waltz, you can implement random file accessing using operating system calls. This facility allows reading from and writing into a file, with the ability to access any given byte of a file. Waltz LISP also provides an interface to assembly language so that an application can conveniently combine both LISP code and assembly language routines.

Waltz LISP lacks many features normally found in Common LISP environments. For example, there is no function for defining global variables (the *defvar* function in Common LISP). Certain short forms, such as *1+* and *1-*, are also not available. Of course, the absence the short forms is not a big problem since you can easily define them for yourself.

The Waltz LISP functions for dealing with property lists of symbols are somewhat different from those of Common LISP. For example, Common LISP's *setf* function, a macro for examining and updating an access form, is missing. The *setf* macro performs the same functions as *setq, rplaca,* and *set,* all of which are included in Waltz LISP. Thus, applications written in Common LISP that make use of *setf* will have to be rewritten.

Although Waltz's *throw* and *catch* forms are syntactically the same as Common LISP's, they don't appear to work in the same way. These forms can be used to exit from a process in a nonlocal manner; their syntax is given in the Waltz LISP users manual, but there are no examples of their use.

Lack of examples is a frequent problem in the Waltz LISP users manual. For many of the functions, only the syntax is described. Of those that do have examples, some are so trivial as to be useless.

Waltz LISP's facilities for general-purpose programming add to the attractiveness of the package. Once you're accustomed to it, Waltz LISP itself is a good LISP environment. However, if you've programmed extensively in Common LISP, you may find that you have to make some fairly large changes to run existing programs.—J.H.

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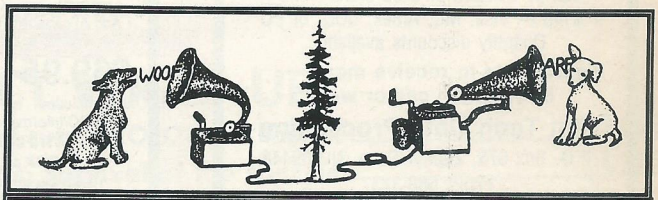

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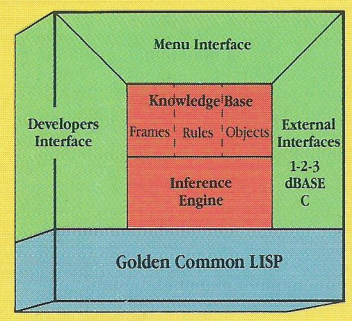

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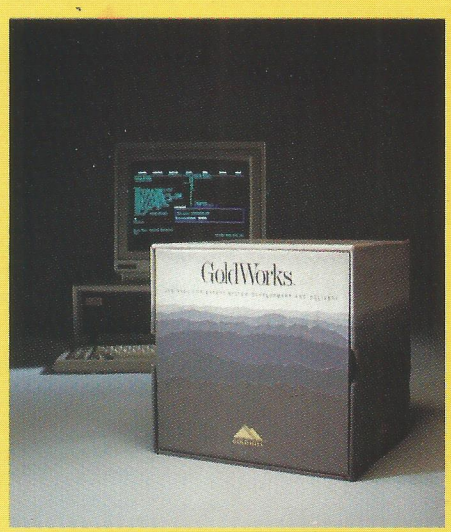

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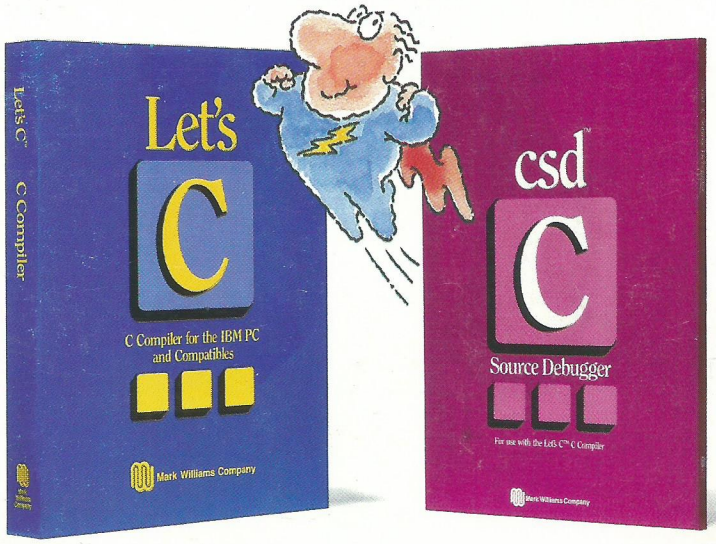

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